

Environmental Radioactivity

Comparison Exercise 2002

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ABSTRACT

The results of the tenth NPL Environmental Radioactivity Comparison Exercise are reported. In general the level of performance is similar to previous comparisons but with a steady improvement for most nuclides. The reported data does suggest however that some analysts are still not making cascade summing corrections. Measurements of ^{238}Pu and ^{239}Pu still exhibit a low bias, and the lack of data returned for many β -emitting nuclides make it difficult to assess performance levels.

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1. INTRODUCTION

This environmental radioactivity comparison was the tenth in a series of similar exercises¹⁻¹⁰ to have been conducted by NPL since 1989. They have evolved over the years in response to the needs of the radioactivity measurement community in the UK and are now well established as part of the analyst's calendar, being particularly important in support of UKAS accreditation in this field. They have also been instrumental in identifying analytical problems and in providing a regular national forum for discussion and technology transfer in this area.

The exercises have been run approximately once every eighteen months by NPL. The range of sample types available for analysis has been mainly aqueous (dilute nitric or hydrochloric acid) although samples based on matrices such as Kaolin⁵ or milk⁶ have also been offered. In the 2002 exercise, six samples were available for analysis:

- i) a 'high-level' mixture of α -, β - and β/γ -emitting radionuclides (@ $\sim 2 \text{ Bq g}^{-1}$ per radionuclide (apart from ^{90}Sr , which was @ $\sim 20 \text{ Bq g}^{-1}$), in dilute nitric acid);
- ii) a 'low-level' mixture of α -, β and β/γ -emitting radionuclides (@ $\sim 2.5 \text{ Bq kg}^{-1}$ per radionuclide (with ^{90}Sr @ $\sim 25 \text{ Bq kg}^{-1}$), in dilute nitric acid);
- iii) a high-level mixture of β/γ -emitting radionuclides ($\sim 2.5 \text{ Bq g}^{-1}$, in dilute hydrochloric/oxalic acid);
- iv) a 'low-level' mixture of β/γ -emitting radionuclides ($\sim 2.5 \text{ Bq kg}^{-1}$, in dilute hydrochloric/oxalic acid).
- v) a 'high-level' mixture of low energy β -emitting radionuclides ($\sim 20 \text{ Bq g}^{-1}$, in water);
- vi) a 'low-level' mixture of low energy β -emitting radionuclides ($\sim 25 \text{ Bq kg}^{-1}$, in water);

2. ORGANISATION

2.1. PARTICIPANTS

A total of 28 participants took part in this exercise, 27 of them reporting data. The majority of the samples taken were of the β/γ -emitting mixtures, with 27 participants taking the high-level mixture and 25 taking the low-level mixture. Uptake of the α/β -emitting mixtures was 17 for the high-level mixture and 21 for the low-level mixture and uptake of the low energy β -emitting mixtures was 15 for the high-level mixture and 11 for the low-level mixture .

The participants came from a wide cross-section of the UK measurement community. A full listing is given in Appendix 1.

2.2. SAMPLES

The samples were given the following identifiers:

- i) high-level α -, β - and β/γ emitting radionuclide mixture - ABHxx/02
- ii) low-level α -, β - and β/γ emitting radionuclide mixture - ABLxx/02
- iii) high-level β/γ -emitting radionuclide mixture - BGHxx/02
- iv) low-level β/γ -emitting radionuclide mixture - BGLxx/02
- v) high-level, low energy β -emitting radionuclide mixture - LBHxx/02
- vi) low-level, low energy β -emitting radionuclide mixture - LBLxx/02

Tables 1-12 summarise the principal radionuclides in the six sample mixtures made available, along with the impurities present in each mixture.

All the radionuclides used in this exercise are either released by the nuclear industry in the course of normal operations or occur naturally in the environment. The following criteria were looked for when choosing the radionuclides:

- (i) that the half-lives were > 50 days;
- (ii) that no obscure species were selected (i.e. all could reasonably be found in the environment or in nuclear-licensed site effluent);
- (iii) that the α/β -emitter samples contained no radionuclides conventionally used as chemical yield tracers;
- (iv) that all the radionuclides were measurable by well-established techniques.

As a result of feedback from the user community, the radionuclides ^{14}C and ^{35}S were included in this comparison. These nuclides arise from the generation of nuclear power and reprocessing of nuclear fuel. Both nuclides can form part of biologically active molecules, which allows them to enter the human food chain.

The timescales allowed for analyses were short so, as in previous years, a list of the radionuclides present in the α/β mixture was provided in advance of the exercise to avoid resource wastage. A similar list was not provided for the β/γ -emitting mixtures, since the measurement technique is non-invasive and enables unambiguous identification of the nuclides present, although the following candidate list of possible γ -emitters was provided:

^7Be , ^{22}Na , ^{46}Sc , ^{54}Mn , ^{56}Co , ^{57}Co , ^{58}Co , ^{60}Co , ^{65}Zn , ^{85}Sr , ^{88}Y , $^{95}\text{Zr}/^{95}\text{Nb}$, $^{106}\text{Ru}/^{106}\text{Rh}$, ^{109}Cd , $^{110\text{m}}\text{Ag}$, ^{113}Sn , ^{124}Sb , ^{125}Sb , ^{133}Ba , ^{134}Cs , ^{137}Cs , ^{139}Ce , ^{144}Ce , ^{153}Gd , ^{154}Eu , ^{155}Eu , ^{160}Tb , ^{170}Tm , ^{203}Hg and ^{207}Bi .

3. CALIBRATION

3.1. ABSOLUTE CALIBRATION

Traceability of measurement is important to all participants, and all nuclides present in the samples were traceable to primary standards of radioactivity. A primary standard is the highest level standard in any hierarchical measurement system. In most cases, primary standards are also absolute standards.

An absolute standard of radioactivity is one that has been measured directly without reference to any other standard of activity; the activity has been determined from count-rate data alone, without reference to any supplementary data determined from previous experiments. In the case of radioactivity standards, absolute standards are generally derived using the 4π -proportional counter- γ -coincidence counting technique for α/γ and β/γ emitting radionuclides¹¹. Those radionuclides decaying by pure α - or pure β -emission can be determined by a variation^{12,13} of this technique.

3.2. SECONDARY STANDARDISATION

Absolute counting techniques are labour intensive and this, coupled with the level of operator expertise required, renders it very expensive; also, there is a limit on the lowest amount of activity that can be measured without the associated uncertainties becoming unacceptably high. A simpler, more rapid method is therefore required for routine calibrations, and this is

achieved by using an absolutely calibrated solution to calibrate a secondary standard instrument. In the case of α/γ or β/γ emitters and some high energy pure β -emitters, this is usually a well-type ionisation chamber that responds only to the γ -rays emitted (in the case of high-energy pure β -emitters, the ionisation chamber measures the Bremsstrahlung radiation). These instruments are normally very stable; for example, the response of the ionisation chambers maintained at NPL has been found to vary by $< 0.1\%$ over 40 years. Other γ -ray detectors (NaI(Tl) or hyperpure Germanium detectors) are applicable but they do not share the long term stability of ionisation chambers. For pure α -emitters and pure β -emitters, there are no suitable secondary standard instruments that have sufficient long term stability; however, liquid scintillation counters can be used, albeit with counting efficiencies which are dependent on such factors as particle energy, spectral shape, chemical format, etc. Pure β -emitters can also be assayed using an ‘efficiency tracing’ technique¹⁴ using ^3H as a tracer nuclide.

4. SOURCE PREPARATION

4.1. PROCUREMENT

The individual radionuclides were obtained from a number of suppliers and had been calibrated in various laboratories, but mostly at NPL. Table 13 summarises the suppliers, the laboratories responsible for the calibrations and the traceability of the measurements.

4.2. PURITY

Each nuclide was checked for impurities either by α -spectrometry, γ -spectrometry or by reference to the original calibration certificate; the impurity levels are shown in Tables 2, 4, 6, 8, 10 and 12.

4.3. ACTIVITY CONFIRMATION

The activity concentrations of the original individual radionuclide solutions were determined either from the calibration certificates or from measurement at NPL, using either absolute methods or secondary standard instruments as described above.

4.4. PREPARATION

The β/γ -emitting mixtures were prepared by (i) diluting standard solutions of the individual radionuclides to approximately equal activity concentrations, (ii) mixing the individual radionuclides and (iii) diluting the mixture down to the required activity levels. The final activity concentration for each nuclide was determined by dividing the initial single-radionuclide activity concentration by the dilution factors as determined from weighing.

Sets of sources (either single-radionuclide or mixed-radionuclide, depending on the dilution stage) were prepared at each dilution stage, for subsequent counting, in order to derive ‘radiometric’ dilution factors to confirm those derived gravimetrically.

A radiometric dilution factor was determined for each principal radionuclide present. These factors were determined by γ -ray spectrometry, using either a NaI(Tl) crystal (single-radionuclide stage) or a hyperpure Ge γ -ray spectrometer (mixed-radionuclide stage).

The α/β mixtures were prepared in the same way, except some of the single-radionuclide dilutions were checked using liquid scintillation counting and the mixed-radionuclide dilutions were verified, as far as possible, by γ -spectrometric determination of the ^{241}Am component. The low energy β mixed-radionuclide dilutions were verified by adding ^{24}Na as a radiometric dilution tracer, with subsequent measurements being made using a well-type NaI(Tl) crystal.

4.4.1. The α/β mixture

Standard solutions of ^{90}Sr , ^{210}Pb , ^{226}Ra , ^{238}Pu , ^{239}Pu and ^{241}Am (10 – 20 ml each, either as extant material at a suitable activity concentration level or material prepared from verified dilutions as described above) were combined and diluted to 7.4 kg with carrier. This diluted mixture was used to make:

- a) 40 x 100 g samples @ 2 Bq g⁻¹ per nuclide (except for ^{90}Sr , which was present at 20 Bq g⁻¹);
- b) 1 x dilution bottle (approximately 100 g diluted to 3 kg).

Bottle (b) was used to make:

- a) 1 x dilution bottle (approximately 700 g diluted to 20 kg).

Finally, bottle (c) was used to make:

- d) 40 x 500 g samples @ 2.5 Bq kg⁻¹ per nuclide (^{90}Sr present at 25 Bq kg⁻¹).

The carrier used consisted of 50 $\mu\text{g g}^{-1}$ each of bismuth, lead, strontium and yttrium as nitrates in 2 M nitric acid. The aqueous matrix acts as a carrier for tritium and there are no suitable carriers for americium, radium or plutonium.

4.4.2. The β/γ mixture

The stock solutions of the individual radionuclides (approximately 1-10 g each) were combined and diluted to 7 kg with carrier. This was used to make:

- a) 50 x 100 g samples @ 2 Bq g⁻¹ per nuclide;
- b) 1 x dilution bottle (approximately 100 g diluted to 3 kg).

Solution (b) was then used to make:

- c) 1 x dilution bottle (approximately 1 kg diluted to 25 kg).

Finally, solution (c) was then used to make:

- d) 50 x 500 g @ 2.5 Bq kg⁻¹.

The carrier used throughout consisted of 50 $\mu\text{g g}^{-1}$ each of barium, caesium, cobalt, europium, sodium, niobium, ruthenium, rhodium and zirconium in 2 M hydrochloric acid/0.1M oxalic acid.

4.4.3. The low energy β mixture

The stock solutions of the individual radionuclides, with ^{24}Na as a radiometric yield tracer (approximately 1-10 g each) were combined and diluted to 6 kg with carrier. This was used to make:

- a) 40 x 100 g samples @ 20 Bq g⁻¹ per nuclide;
- b) 1 x dilution bottle (approximately 100 g diluted to 3 kg).

Solution (b) was then used to make:

- c) 1 x dilution bottle (approximately 700 g diluted to 20 kg).

Finally, solution (c) was then used to make:

- d) 40 x 500 g @ 25 Bq kg⁻¹.

The carrier used throughout consisted of 4 $\mu\text{g g}^{-1}$ of sodium hydroxide, 5 $\mu\text{g g}^{-1}$ sodium carbonate and 5 $\mu\text{g g}^{-1}$ sodium sulphate in water.

To further validate the overall gravimetric dilution factors, selected customers samples of (a) and (d) were assayed by γ -ray spectrometry when possible.

5. TREATMENT OF DATA

5.1. NUMERICAL DATA

As in previous years, data reporting forms were prepared and distributed with the samples, with participants having the additional option of reporting their data electronically. The data returned were used in conjunction with the reference values to calculate two parameters. First, the deviation from the reference value was calculated, as a percentage:

$$\text{Deviation (\%)} = \frac{(\text{Analyst's result} - \text{Reference value}) \times 100}{\text{Reference value}}$$

The value of the u-statistic¹⁵ was also calculated:

$$u - \text{statistic} = \frac{(\text{Analyst's result} - \text{Reference value})}{\sqrt{(\text{Analyst's uncertainty}^2 + \text{Uncertainty on reference value}^2)}}$$

This provides an indication of agreement between the two values. The uncertainty to be used is the standard uncertainty (where the coverage factor, $k = 1$).

This statistic is compared with values in the t-statistic tables¹⁶ and can be interpreted as set out in Table 10.

Note that, throughout this report, the term ‘discrepant’ is used to describe data yielding a u-statistic > 3.29.

5.2. UNCERTAINTIES

Uncertainties for the reference values have all been estimated in accordance with the internationally-accepted protocols^{17,18}. Unless otherwise stated, all the uncertainties in this report are stated as standard uncertainties with a coverage factor of $k = 1$ (i.e. at the 68 % confidence level).

5.3. NUCLEAR DECAY DATA

The data used by the participants are discussed later; the data used by NPL in preparing and validating the samples are all given in Table 11. In each case, the γ -ray emission probabilities, P_γ , are only given if they exceed 1%.

5.4. PRESENTATION

The results of all the u-tests carried out are summarised in Tables 16 -18.

The participants' results for the radionuclides included in the samples by NPL are tabulated in Tables 19-53 and are plotted in Figures 1-70. Other radionuclides reported by the participants are given in Table 54.

5.5. CONFIDENTIALITY

As is usual in these exercises, the relationship between the participants and the results remains confidential to NPL.

6. RESULTS FOR α -EMITTERS AND PURE β -EMITTERS

6.1. GENERAL COMMENTS

In response to feedback from the user community, the same activity levels were offered up for analysis as in the previous comparison, although the component radionuclides were changed. The radionuclides ^{65}Zn , ^{124}Sb , ^{125}Sb and ^{99}Tc were dropped and ^{14}C , ^{35}S and ^{95}Zr were included. The ^{14}C and ^{35}S were prepared together with tritium to provide a low energy mixture. The overall number of results returned has not increased; this is particularly worrying for ^{90}Sr , where analytical problems have been evident from recent exercises and where wider participation was perhaps expected.

All participants used radioanalytical techniques to isolate the individual nuclides from the mixtures. The standards used, when reported, were from national standards laboratories or other centres providing traceability. Similarly, the nuclear data sources cited were recognised centres, and the wide usage of the Radiochemical Manual¹⁹ was evident.

6.2. ^3H

As in previous exercises, participants separated the ^3H by distillation, with a few laboratories carrying this out at low-temperature and some laboratories using a variety of different combustion techniques. There were two clear outliers at the high level, and it is not clear from the supplementary data supplied by participants what the reasons for this are, but the proportion of correct values at each of the two levels is very similar to that observed in the

last exercise. The high biases observed last exercise haven't been seen this time, although it should be noted that because these are small data sets it is difficult to draw conclusions from them.

6.3. ^{90}Sr

Surprisingly few data were reported for this nuclide, at either activity level. It is very difficult, therefore, to draw conclusions concerning the overall level of performance or to discern trends in performance since recent exercises. In preparing the samples for analysis, most laboratories used the basic principle of allowing the yttrium to ingrow into purified strontium and then separating and counting the yttrium. Most used Cerenkov counting to measure their samples, with one laboratory using a gas-flow proportional counter to measure the ^{90}Sr in the low-level sample, whilst another laboratory used ICP-MS. The use of ^{85}Sr as a tracer was cited by most laboratories.

Of the data returned, for the higher level mixture all were in good agreement with NPL but for the lower level mixture two-thirds of the data returned was unambiguously in agreement, whilst the other one-third was discrepant

6.4. ^{210}Pb

This radionuclide was included for the first time at the last comparison. The wide dissemination of ^{210}Pb is due to (i) the long half-life of ^{226}Ra , coupled with the solubility of the latter in fresh water and sea water, (ii) the outgassing of ^{222}Rn , resulting in the atmospheric distribution of this nuclide and its decay products, and (iii) the fairly long half-life of ^{210}Pb and its solubility in aqueous systems.

Unfortunately only two participants opted to measure this radionuclide, which means no useful conclusions can be drawn from the results.

6.5. ^{226}Ra

This radionuclide too is both long-lived and water-soluble, and is consequently widely distributed in the environment. As in the last comparison, few participants (five) opted to measure it; however, at the higher level most reported results agreed well with the reference value. The small number of reported results precludes any general conclusions.

6.6. $^{238}\text{Pu}/^{239}\text{Pu}$

The numbers of results returned for these nuclides was similar to the previous exercise. Nearly all participants used ion exchange and/or extraction chromatography to separate the nuclides from the mixture, followed by electrodeposition onto discs and subsequent assay using α -spectrometry.

The low biases observed in the last exercise, for both nuclides and at both levels, are still evident at the higher activity level but less so at the lower level. It had been expected that the development of primary standards for these nuclides at NPL would have overcome the metrological problems apparent from earlier exercises, and it is worrying that these problems are persisting even though there is a definite improvement. Most analysts used ^{236}Pu or ^{242}Pu yield tracers from reliable suppliers.

6.7. ^{241}Am

Most of the participants carried out ion exchange or extraction chromatography to separate the nuclide, followed by electrodeposition prior to assay by α -spectrometry; with some opting to use γ -ray spectrometry. The nuclide ^{241}Am was used as a tracer by many laboratories. There is a low bias evident at the lower activity level, although 3 deviant results is the main driving force of this.

7. RESULTS FOR β/γ -EMITTERS

7.1. GENERAL COMMENTS

The majority of the data returned was from analyses of the β/γ -emitting nuclides, in common with previous exercises. A similar nuclide mix to last time was adopted, with, ^{65}Zn , ^{124}Sb , ^{125}Sb and ^{207}Bi being dropped and $^{106}\text{Ru}/^{106}\text{Rh}$, ^{95}Zr and ^{57}Co being added.

Sample preparation is inevitably simpler than for the α/β analyses. Most participants transferred the sample, without dilution, to a known geometry for γ -ray spectrometry, whilst around some carried out a dilution, a volume reduction or deposition to a solid matrix prior to homogenisation. All used semiconductor detectors, with p-type and n-type detectors being equally popular. Commercially-available data analysis software was universally used, with 'in-house' data libraries becoming more popular. NPL²³ and IAEA²² nuclear data were the most widely adopted of several centres cited, and the very wide usage of mixed radionuclide standards from NPL or Amersham continues.

7.2. ^{22}Na

This is a positron emitter (with a 9.5 % electron-capture branch). Again there is a large proportion of discrepant data, at the higher of the two activity levels. The problems encountered are doubtless largely due to the presence of ^{154}Eu in the mixture, which also emits γ -rays at approximately 1274 keV and is therefore likely to complicate the analysis. It is possible that, in some cases, a correction has either not been applied or has been applied incorrectly.

7.3. ^{57}Co

This nuclide is a low energy γ -emitter which is used as a calibration nuclide. The quality of the results was generally high, being slightly better at the low level.

7.4. ^{60}Co

This nuclide is well known as an activation product and as a high-energy calibration point for mixed-radionuclide type standards. The data returned are encouraging in that the proportion of discrepant data remains low although for the high level solution there was a definite low bias which is not expected for a calibration point nuclide.

7.5. ^{95}Zr

The results for this nuclide shows quite a wide spread, which reflects the interferences observed with ^{154}Eu ; however it is encouraging to note that the number of discrepant results has fallen since the last time this nuclide was included in a comparison, suggesting that the mutual interference problem may no longer be a problem for many analysts.

7.6. $^{106}\text{Ru}/^{106}\text{Rh}$

Ruthenium-106 is a fission product nuclide and decays via a short lived daughter nuclide, ^{106}Rh , with low abundance γ rays. It may be volatile and can therefore be distributed over a wide area, as happened at the Chernobyl accident. The low bias shown in the results could be due to a number of factors, including cascade summing.

7.7. ^{134}Cs

This nuclide occurs in nuclear waste and is present in various ecosystems. This nuclide has been included in many previous exercises on account of its being very widely assayed in environmental samples. The need for cascade summing corrections²⁰ has been emphasised but, curiously, the low biases of the reported data suggest that they are still not being applied in some cases. The bias is less clear at the lower activity level, probably because of the larger uncertainties on the measurements.

7.8. ^{137}Cs

This is a fission product and is also used as a calibration radionuclide. It occurs widely in the environment. Overall performance has improved compared to the last exercise with a significant reduction in the levels of discrepant data and a greater proportion (84 %) of the submitted data are unambiguously correct.

7.9. ^{154}Eu

This nuclide is formed by neutron activation of stable europium, and emits γ -rays across the whole γ -ray energy range. It is quite possible to misidentify this nuclide as one of several others, e.g. ^{152}Eu , ^{56}Co , ^{124}Sb , ^{108}Ag , ^{95}Zr and ^{22}Na .

There are far less discrepant results at the lower level than in the last exercise, but with the level of discrepant data remaining the same for the higher level mixture. Improvements may be possibly due to better corrections being made for the presence of ^{22}Na , which will contribute to the 1274 keV peak. This nuclide exhibits cascade summing effects and there seems to be an overall small low bias suggesting that some analysts have not applied a correction for this.

7.10. ^{155}Eu

This is another fission product, albeit with a low fission yield. Measurement of this nuclide is complicated by the fact that it emits (low energy) γ -rays in an energy range where the rate of change of detector efficiency with energy is large. The results at the lower level are similar to last time, and performance at the higher level has improved, with fewer discrepant data now being evident.

8. DISCUSSION

8.1. α -EMITTERS

The number of measurements of α -emitting radionuclides performed was similar to the last exercise. The level of performance for ^{241}Am and the plutonium nuclides at the higher level was similar to last time but there was a marked improvement at low level for the plutonium

nuclides, especially for ^{238}Pu even though the low biases for the plutonium nuclides have again been observed.

The measurements of ^{226}Ra were not as successful as last year but with only a small number of laboratories assaying this nuclide there is insufficient data from which to draw any conclusions about performance nationally.

It should be noted that NPL recently participated in an international comparison of ^{238}Pu with a number of other national measurement institutes. The final report of this exercise is in preparation, but preliminary data indicate that the NPL value will not differ significantly from the overall mean value, thus giving NPL additional confidence in its standard.

8.2. β -EMITTERS

Following requests from the user community, ^{14}C and ^{35}S were added to tritium to provide a low energy mixture, whilst ^{90}Sr and ^{210}Pb were again supplied in the α/β mixture. As in the last comparison, the number of results returned was disappointingly low for most of these nuclides (the return for tritium being rather better). In particular it was surprising that considering there had been an expression of interest from the user community for ^{14}C and ^{35}S , the number of results returned was so low. In light of the poor return, therefore, it is difficult to draw conclusions about countrywide performance from the corpus of data available.

8.3. β/γ -EMITTERS

The results appear to demonstrate several points:

- (i) The overall level of discrepant data is still falling, most notably for ^{137}Cs at the higher activity level (2 Bq g^{-1}), suggesting that a greater number of analysts are carrying out more rigorous estimates of uncertainties.
- (ii) Some analysts experienced problems with measuring ^{22}Na and ^{95}Zr , this may have been due to the presence of ^{154}Eu .
- (iii) Cascade summing effects are still evident, particularly with measurements of ^{134}Cs and also to a certain extent ^{106}Ru .
- (iv) Performance for one of the radionuclides used in detector calibration (^{137}Cs) has improved still further in that the proportions of unambiguously correct results have clearly increased, now being 84 %.

8.4. GENERAL COMMENTS

8.4.1. Nuclear Decay Data

The wide usage of data from internationally recognised sources continues. The vast majority of data cited for the α - and pure β -emitters was taken from the Radiochemical Manual¹⁹, but the data for β/γ -emitters was also drawn from other sources, most notably NPL²³, IAEA²², JEF 2.2²¹ and Browne and Firestone. Many participants used 'in-house' data libraries for the assay of the β/γ -emitters; this is sound practice provided that the data used is from a reliable source. A small number of participants used manufacturers' data, which is acceptable practice provided that the user checks the provenance of the data and makes adjustments as necessary.

The number of laboratories using data that has not come from a properly evaluated and maintained database (or are of unknown origin) is now very small. Analysts having any doubts as to the reliability of their data should consult NPL, who will gladly advise.

8.4.2. Standards

Of those laboratories who cited standards, all used β/γ -emitting standards of the mixed radionuclide type for measuring the β/γ -emitters with one laboratory supplementing such a calibration with single nuclide standards; for the α/β assays, the standards and chemical yield tracers cited had been obtained from NPL, NIST, Amersham or AEA Technology.

9. CONCLUSIONS

There are mixed conclusions to be drawn from this comparison exercise.

On the positive side, fewer discrepant results were submitted for the β/γ -emitters than in past exercises, possibly as a result of analysts compiling more comprehensive uncertainty budgets than before. Performance in the assay of many β/γ -emitters, including calibration nuclides, continues to improve. The usage of traceable standards and reliable nuclear data remains high.

There are, however, some areas of concern. The assay of the plutonium nuclides are still exhibiting low biases; cascade summing effects are still evident (e.g. for ^{134}Cs measurements); and the lack of reported data for ^{90}Sr means that the problems evident from previous comparisons may still remain.

That said, it is also clear that many laboratories are now measuring β/γ -emitters at these levels, in an aqueous matrix, with little difficulty and, indeed, some have expressed interest in moving on to a non-aqueous matrix to more closely mimic performance for field samples. It may now be appropriate to try such a matrix for the next exercise, perhaps at one activity level and with the less problematic nuclides.

Concluding, it can be said:

- (i) there remains scope for improvement in performance for specific β/γ -emitters, notably ^{22}Na , ^{95}Zr , ^{106}Ru and ^{134}Cs ;
- (ii) more data are required for the β -emitting samples to enable national performance levels to be monitored and any specific metrological problems to be identified;
- (iii) NPL needs to address specific assay problems (e.g. ^{90}Sr , plutonium nuclides) in parallel with future comparisons;
- (iv) consideration should be given to including a non-aqueous matrix in the next exercise.

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11.

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Table 1 - ABHxx/02 - principal radionuclides.

Radionuclide	Decay mode	Activity concentration @ 1200 GMT 01/10/02 (Bq g ⁻¹)	Standard uncertainty (<i>k</i> = 1) (Bq g ⁻¹)
⁹⁰ Sr	β ⁻	19.980	0.160
²¹⁰ Pb	β ⁻ /γ	3.420	0.160
²²⁶ Ra	α/γ	1.979	0.030
²³⁸ Pu	α	2.000	0.016
²³⁹ Pu	α	1.991	0.023
²⁴¹ Am	α/γ	1.996	0.018

Table 2 - ABHxx/02 - impurities.

Radionuclide	Decay mode	Activity concentration @ 1200 GMT 1/10/02 (Bq g ⁻¹)	Standard uncertainty (<i>k</i> = 1) (Bq g ⁻¹)
²⁴¹ Pu	β ⁻	0.02	-
unspecified α-emitters	α	< 0.001	-

Table 3 - ABLxx/02 – principal radionuclides.

Radionuclide	Decay mode	Activity concentration @ 1200 GMT 01/10/02 (Bq kg ⁻¹)	Standard uncertainty (<i>k</i> = 1) (Bq kg ⁻¹)
⁹⁰ Sr	β ⁻	24.69	0.55
²¹⁰ Pb	β ⁻ /γ	4.230	0.210
²²⁶ Ra	α/γ	2.445	0.063
²³⁸ Pu	α	2.471	0.055
²³⁹ Pu	α	2.460	0.058
²⁴¹ Am	α/γ	2.466	0.056

Table 4 - ABLxx/02 - impurities.

Radionuclide	Decay mode	Activity concentration @ 1200 GMT 1/10/02 (Bq kg ⁻¹)	Standard uncertainty (<i>k</i> = 1) (Bq kg ⁻¹)
²⁴¹ Pu	β ⁻	0.025	-
unspecified α-emitters	α	< 0.001	-

Table 5 - LBHxx/02 – principal radionuclides.

Radionuclide	Decay mode	Activity concentration @ 1200 GMT 01/10/02 (Bq g ⁻¹)	Standard uncertainty (<i>k</i> = 1) (Bq g ⁻¹)
³ H	β ⁻	20.04	0.18
¹⁴ C	β ⁻	19.46	0.12
³⁵ S	β ⁻	20.22	0.14

Table 6 - LBHxx/02 - impurities.

Radionuclide	Decay mode	Activity concentration @ 1200 GMT 1/10/02 (Bq g ⁻¹)	Standard uncertainty (<i>k</i> = 1) (Bq g ⁻¹)
³⁶ Cl	β ⁻	0.0022	0.00055

Table 7 - LBLxx/02 – principal radionuclides.

Radionuclide	Decay mode	Activity concentration @ 1200 GMT 01/10/02 (Bq kg ⁻¹)	Standard uncertainty (<i>k</i> = 1) (Bq kg ⁻¹)
³ H	β ⁻	25.13	0.56
¹⁴ C	β ⁻	24.41	0.53
³⁵ S	β ⁻	25.36	0.55

Table 8 - LBLxx/02 - impurities.

Radionuclide	Decay mode	Activity concentration @ 1200 GMT 1/10/02 (Bq g ⁻¹)	Standard uncertainty (<i>k</i> = 1) (Bq g ⁻¹)
³⁶ Cl	β ⁻	0.0028	0.0007

Table 9 - Principal radionuclides - BGHxxx/02

Radionuclide	Decay mode	Activity concentration @ 1200 GMT 01/10/02 (Bq g ⁻¹)	Standard uncertainty (<i>k</i> = 1) (Bq g ⁻¹)
²² Na	e.c., β ⁺ /γ	2.024	0.010
⁵⁷ Co	e.c./ γ	2.008	0.020
⁶⁰ Co	β ⁻ /γ	2.009	0.008
⁹⁵ Zr	β ⁻ /γ	1.943	0.032
¹⁰⁶ Ru	β ⁻ /γ	2.012	0.011
¹³⁴ Cs	β ⁻ /γ	2.025	0.016
¹³⁷ Cs	β ⁻ ,β ⁻ /γ	2.015	0.015
¹⁵⁴ Eu	β ⁻ /γ	2.081	0.017
¹⁵⁵ Eu	β ⁻ /γ	2.041	0.024

Table 10 - BGHxxx/02 impurities

Radionuclide	Decay mode	Activity concentration @1200 GMT 1/10/02 (Bq g ⁻¹)	Standard uncertainty (<i>k</i> = 1) (Bq kg ⁻¹)
¹⁵² Eu	β ⁻ /γ	0.044	0.010

Table 11 - Principal radionuclides – BGLxxx/02

Radionuclide	Decay mode	Activity concentration @ 1200 GMT 01/10/02 (Bq kg ⁻¹)	Standard uncertainty ($k = 1$) (Bq kg ⁻¹)
²² Na	e.c., β^+/γ	2.670	0.054
⁵⁷ Co	e.c./ γ	2.649	0.058
⁶⁰ Co	β^-/γ	2.651	0.053
⁹⁵ Zr	β^-/γ	2.564	0.066
¹⁰⁶ Ru	β^-/γ	2.654	0.054
¹³⁴ Cs	β^-/γ	2.672	0.056
¹³⁷ Cs	$\beta^-,\beta^-/\gamma$	2.659	0.056
¹⁵⁴ Eu	β^-/γ	2.745	0.058
¹⁵⁵ Eu	β^-/γ	2.693	0.062

Table 12 - BGLxxx/02 - impurities

Radionuclide	Decay mode	Activity concentration @1200 GMT 1/10/02 (Bq kg ⁻¹)	Standard uncertainty ($k = 1$) (Bq kg ⁻¹)
¹⁵² Eu	β^-/γ	0.058	0.013

Table 13 - Radionuclide Provenance

Radionuclide	Origin	Calibrating Laboratory	Traceability
Sr-90	NA, UK	NPL	UK Primary Standard/NPL
Pb-210	DKD, Germany	DKD	German Primary Standard/PTB
Ra-226	CMI, Czech Republic	NPL	UK Primary Standard/NPL
Pu-238	TENEX, Russia	NPL	UK Primary Standard/NPL
Pu-239	TENEX, Russia	NPL	UK Primary Standard/NPL
Am-241	NA, UK	NPL	UK Primary Standard/NPL
H-3	NA, UK	NPL	UK Primary Standard/NPL
C-14	NA, UK	NPL	UK Primary Standard/NPL
S-35	NA, UK	NPL	UK Primary Standard/NPL
Na-22	PE, USA	NPL	UK Primary Standard/NPL
Co-57	NA, UK	NPL	UK Primary Standard/NPL
Co-60	NA, UK	NPL	UK Primary Standard/NPL
Zr-95	NPL, UK	NPL	UK Primary Standard/NPL
Ru-106	NA, UK	NPL	UK Primary Standard/NPL
Cs-134	NA, UK	NPL	UK Primary Standard/NPL
Cs-137	NA, UK	NPL	UK Primary Standard/NPL
Eu-154	NA, UK	NPL	UK Primary Standard/NPL
Eu-155	IIR, Czech Republic	NPL	UK Primary Standard/NPL

CMI: Czech Metrological Institute, Czech Republic
 TENEX: TENEX All-Union Foreign Economic Association Techsnabexport, Russia
 NA: Nycomed-Amersham, UK
 DKD: Deutscher Kalibrierdienst, Germany
 PTB: Physikalisch-Technische Bundesanstalt, Germany
 IIR: Inspektorát pro Ionizující Zářeni, Czech Republic
 PE: PerkinElmer, USA

Table 14- Criteria for u-tests

Value	Conclusion
$u < 1.64$	The values do not differ significantly
$1.64 < u < 1.96$	The values probably do not differ significantly but more data are required to confirm this
$1.96 < u < 2.58$	One cannot say whether there is a significant difference without further data
$2.58 < u < 3.29$	The values probably differ significantly but more data are required to confirm this
$3.29 < u$	The values differ significantly

Table 15- Nuclear decay data

Nuclide	Half life (days)	E_{γ} (keV)	P_{γ} (%)	Reference
^3H	4504 ± 8	-	-	[21]
^{14}C	$(2.093 \pm 0.015) \times 10^6$	-	-	[23]
^{22}Na	950.8 ± 0.9	1274.5	99.935 ± 0.015	[22]
^{35}S	87.5	-	-	[23]
^{57}Co	271.79 ± 0.09	14.4	9.16 ± 0.15	[22]
		122.1	85.60 ± 0.17	[22]
		136.5	10.68 ± 0.08	[22]
^{60}Co	1925.5 ± 0.5	1173.2	99.857 ± 0.022	[22]
		1332.5	99.983 ± 0.006	[22]
^{90}Sr	10460 ± 60	-	-	[22]
^{95}Zr	64.03 ± 0.03	724.199	43.9 ± 0.8	[26]
		756.729	54.5 ± 0.5	[26]
^{106}Ru	368.2 ± 1.2	511.9	20.7 ± 0.6	[22]
		621.8	9.81 ± 0.58	[23]
		1050.4	1.50 ± 0.11	[22]
^{134}Cs	754.28 ± 0.22	475.4	1.49 ± 0.02	[22]
		563.2	8.36 ± 0.03	[22]
		569.3	15.39 ± 0.06	[22]

Nuclide	Half life (days)	E_γ (keV)	P_γ (%)	Reference
		604.7	97.63 ± 0.06	[22]
		795.9	85.4 ± 0.3	[22]
		801.9	8.69 ± 0.03	[22]
		1168.0	1.792 ± 0.007	[22]
		1365.2	3.016 ± 0.011	[22]
^{137}Cs	11020 ± 60	661.7	85.1 ± 0.2	[22]
^{154}Eu	3136.8 ± 2.9	123.1	41.2 ± 0.5	[22]
		247.9	6.95 ± 0.09	[22]
		591.8	4.99 ± 0.06	[22]
		692.4	1.80 ± 0.03	[22]
		723.3	20.2 ± 0.2	[22]
		756.8	4.58 ± 0.06	[22]
		873.2	12.24 ± 0.15	[22]
		996.3	10.48 ± 0.13	[22]
		1004.7	18.2 ± 0.2	[22]
		1274.4	35.0 ± 0.4	[22]
^{155}Eu	1770 ± 50	60.0	1.13 ± 0.05	[22]/[24]
		86.5	30.7 ± 0.7	[24]
		105.3	21.2 ± 0.5	[24]
^{210}Pb	$(8.15 \pm 0.08) \times 10^3$	46.5	4.5 ± 0.3	[19]
^{226}Ra	$(5.844 \pm 0.026) \times 10^5$	186.0	32.8 ± 0.3	[19]
^{238}Pu	$(3.203 \pm 0.011) \times 10^4$	-	-	[25]
^{239}Pu	$(8.806 \pm 0.011) \times 10^6$	-	-	[25]
^{241}Am	$(1.5785 \pm 0.0024) \times 10^5$	59.5	36.0 ± 0.4	[22]

Table 16 - Results of u-tests for α/β -emitters

NUCLIDE	LIMITS	NUMBER OF RESULTS HIGH LEVEL	NUMBER OF RESULTS LOW LEVEL
⁹⁰ Sr	< 1.64	5	7
	1.64 - 1.96	0	0
	1.96 - 2.58	0	0
	2.58 - 3.29	0	0
	> 3.29	1	3
²¹⁰ Pb	< 1.64	0	2
	1.64 - 1.96	0	0
	1.96 - 2.58	0	0
	2.58 - 3.29	0	0
	> 3.29	0	0
²²⁶ Ra	< 1.64	3	1
	1.64 - 1.96	0	0
	1.96 - 2.58	0	1
	2.58 - 3.29	1	0
	> 3.29	0	1
²³⁸ Pu	< 1.64	5	10
	1.64 - 1.96	1	0
	1.96 - 2.58	1	1
	2.58 - 3.29	1	0
	> 3.29	0	1
²³⁹ Pu	< 1.64	7	10
	1.64 - 1.96	0	1
	1.96 - 2.58	1	1
	2.58 - 3.29	0	0
	> 3.29	0	0
²⁴¹ Am	< 1.64	7	7
	1.64 - 1.96	0	0
	1.96 - 2.58	1	2
	2.58 - 3.29	2	0
	> 3.29	1	2

Table 17 - Results of u-tests for low energy β -emitters

NUCLIDE	LIMITS	NUMBER OF RESULTS HIGH LEVEL	NUMBER OF RESULTS LOW LEVEL
³ H	< 1.64	13	6
	1.64 - 1.96	1	0
	1.96 - 2.58	1	0
	2.58 - 3.29	0	0
	> 3.29	2	0
¹⁴ C	< 1.64	0	2
	1.64 - 1.96	0	1
	1.96 - 2.58	0	0
	2.58 - 3.29	1	0
	> 3.29	0	1
³⁵ S	< 1.64	2	2
	1.64 - 1.96	0	0
	1.96 - 2.58	0	0
	2.58 - 3.29	0	0
	> 3.29	1	1

Table 18 - Results of u-tests for β/γ -emitters

NUCLIDE	LIMITS	NUMBER OF RESULTS HIGH LEVEL	NUMBER OF RESULTS LOW LEVEL
²² Na	< 1.64	9	13
	1.64 - 1.96	0	0
	1.96 - 2.58	0	0
	2.58 - 3.29	0	2
	> 3.29	10	0
⁵⁷ Co	< 1.64	15	13
	1.64 - 1.96	0	2
	1.96 - 2.58	2	1
	2.58 - 3.29	2	0
	> 3.29	0	0
⁶⁰ Co	< 1.64	12	13
	1.64 - 1.96	1	1
	1.96 - 2.58	1	0
	2.58 - 3.29	2	1
	> 3.29	3	1
⁹⁵ Zr	< 1.64	10	9
	1.64 - 1.96	2	0
	1.96 - 2.58	2	2
	2.58 - 3.29	1	0
	> 3.29	4	2
¹⁰⁶ Ru	< 1.64	6	6
	1.64 - 1.96	1	1
	1.96 - 2.58	2	0
	2.58 - 3.29	2	0
	> 3.29	7	0
¹³⁴ Cs	< 1.64	8	12
	1.64 - 1.96	0	1
	1.96 - 2.58	2	2
	2.58 - 3.29	0	0
	> 3.29	9	1
¹³⁷ Cs	< 1.64	13	16
	1.64 - 1.96	2	0
	1.96 - 2.58	2	0
	2.58 - 3.29	1	0
	> 3.29	1	0
¹⁵⁴ Eu	< 1.64	10	16
	1.64 - 1.96	0	0
	1.96 - 2.58	2	0
	2.58 - 3.29	1	0
	> 3.29	6	0
¹⁵⁵ Eu	< 1.64	12	11
	1.64 - 1.96	3	1
	1.96 - 2.58	2	2
	2.58 - 3.29	1	1
	> 3.29	1	0

Table 19 - Results for ^{90}Sr (low level)

Sample	NPL Data		Analyst Data			
					Deviation	u-test
					(%)	statistic
ABL***/02	^{90}Sr	$\pm$	^{90}Sr	$\pm$		
	Bq kg ⁻¹	Bq kg ⁻¹	Bq kg ⁻¹	Bq kg ⁻¹		
ABL003/02	24.69	0.55	22.1	0.5	-10.49	3.48
ABL004/02	24.69	0.55	22.9	3.86	-7.25	0.46
ABL005/02	24.69	0.55	26.1	1.87	5.71	0.72
ABL010/02	24.69	0.55	21.87	0.5	-11.42	3.79
ABL012/02	24.69	0.55	17.32	1.46	-29.85	4.72
ABL017/02	24.69	0.55	26	1.8	5.31	0.70
ABL020/02	24.69	0.55	27.7	1.8	12.19	1.60
ABL021/02a	24.69	0.55	24.1	1.3	-2.39	0.42
ABL021/02b	24.69	0.55	23.7	1.3	-4.01	0.70
ABL021/02c	24.69	0.55	23.1	1.3	-6.44	1.13

Table 20 - Results for ^{210}Pb (low level)

Sample	NPL Data		Analyst Data			
					Deviation	u-test
					(%)	statistic
ABL***/02	^{210}Pb	$\pm$	^{210}Pb	$\pm$		
	Bq kg ⁻¹	Bq kg ⁻¹	Bq kg ⁻¹	Bq kg ⁻¹		
ABL012/02	4.23	0.21	3.84	0.31	-9.22	1.04
ABL023/02	4.23	0.21	3.72	0.23	-12.06	1.64

Table 21 – Results for ^{226}Ra (low level)

Sample	NPL Data		Analyst Data			
					Deviation	u-test
					(%)	statistic
ABL***/02	^{226}Ra	$\pm$	^{226}Ra	$\pm$		
	Bq kg ⁻¹	Bq kg ⁻¹	Bq kg ⁻¹	Bq kg ⁻¹		
ABL005/02	2.445	0.063	2.05	0.14	-16.16	2.57
ABL012/02	2.445	0.063	0.66	0.04	-73.01	23.92
ABL020/02	2.445	0.063	2.46	0.27	0.61	0.05

Table 22 – Results for ^{238}Pu (low level)

Sample	NPL Data		Analyst Data		Deviation	u-test
					(%)	statistic
ABL***/02	^{238}Pu	$\pm$	^{238}Pu	$\pm$		
	Bq kg ⁻¹	Bq kg ⁻¹	Bq kg ⁻¹	Bq kg ⁻¹		
ABL003/02	2.471	0.055	2.42	0.09	-2.06	0.48
ABL004/02	2.471	0.055	2.361	0.21	-4.45	0.51
ABL005/02	2.471	0.055	2.35	0.215	-4.90	0.55
ABL009/02	2.471	0.055	2.4	0.1	-2.87	0.62
ABL010/02	2.471	0.055	2.07	0.07	-16.23	4.50
ABL012/02	2.471	0.055	2.62	0.21	6.03	0.69
ABL017/02	2.471	0.055	2.4	0.14	-2.87	0.47
ABL020/02	2.471	0.055	2.36	0.065	-4.49	1.30
ABL021/02a	2.471	0.055	2.43	0.16	-1.66	0.24
ABL021/02b	2.471	0.055	2.05	0.2	-17.04	2.03
ABL021/02c	2.471	0.055	2.42	0.11	-2.06	0.41
ABL023/02	2.471	0.055	2.32	0.11	-6.11	1.23

Table 23 – Results for ^{239}Pu (low level)

Sample	NPL Data		Analyst Data		Deviation	u-test
					(%)	statistic
ABL***/02	^{239}Pu	$\pm$	^{239}Pu	$\pm$		
	Bq kg ⁻¹	Bq kg ⁻¹	Bq kg ⁻¹	Bq kg ⁻¹		
ABL003/02	2.460	0.058	2.44	0.09	-0.81	0.19
ABL004/02	2.460	0.058	2.291	0.204	-6.87	0.80
ABL005/02	2.460	0.058	2.53	0.226	2.85	0.30
ABL009/02	2.460	0.058	2.4	0.1	-2.44	0.52
ABL010/02	2.460	0.058	2.21	0.08	-10.16	2.53
ABL012/02	2.460	0.058	2.55	0.2	3.66	0.43
ABL017/02	2.460	0.058	2.44	0.14	-0.81	0.13
ABL020/02	2.460	0.058	2.379	0.064	-3.29	0.94
ABL021/02a	2.460	0.058	2.67	0.17	8.54	1.17
ABL021/02b	2.460	0.058	2.08	0.20	-15.45	1.82
ABL021/02c	2.460	0.058	2.64	0.12	7.32	1.35
ABL023/02	2.460	0.058	2.33	0.11	-5.28	1.05

Table 24 – Results for ^{241}Am (low level)

Sample	NPL Data		Analyst Data			
					Deviation	u-test
					(%)	statistic
ABL***/02	^{241}Am	$\pm$	^{241}Am	$\pm$		
	Bq kg^{-1}	Bq kg^{-1}	Bq kg^{-1}	Bq kg^{-1}		
ABL003/02	2.466	0.056	2.44	0.08	-1.05	0.27
ABL004/02	2.466	0.056	2.411	0.137	-2.23	0.37
ABL005/02	2.466	0.056	2.01	0.221	-18.49	2.00
ABL006/02	2.466	0.056	2.18	0.19	-11.60	1.44
ABL009/02	2.466	0.056	2.5	0.25	1.38	0.13
ABL010/02	2.466	0.056	1.3	0.05	-47.28	15.53
ABL012/02	2.466	0.056	1.76	0.14	-28.63	4.68
ABL017/02	2.466	0.056	2.56	0.13	3.81	0.66
ABL020/02	2.466	0.056	2.291	0.063	-7.10	2.08
ABL022/02	2.466	0.056	2.66	0.12	7.87	1.46
ABL023/02	2.466	0.056	2.41	0.12	-2.27	0.42

Table 25 – Results for ^{90}Sr (high level)

Sample	NPL Data		Analyst Data			
					Deviation	u-test
					(%)	statistic
ABH***/02	^{90}Sr	$\pm$	^{90}Sr	$\pm$		
	Bq g^{-1}	Bq g^{-1}	Bq g^{-1}	Bq g^{-1}		
ABH003/02	19.98	0.16	18.83	1.21	-5.76	0.94
ABH004/02	19.98	0.16	20.4	1.67	2.10	0.25
ABH009/02	19.98	0.16	17.66	0.31	-11.61	6.65
ABH016/02a	19.98	0.16	19.7	0.9	-1.40	0.31
ABH016/02b	19.98	0.16	20.9	1	4.60	0.91
ABH016/02c	19.98	0.16	19.1	0.9	-4.40	0.96

Table 26– Results for ^{226}Ra (high level)

Sample	NPL Data		Analyst Data			
					Deviation	u-test
					(%)	statistic
ABH***/02	^{226}Ra	$\pm$	^{226}Ra	$\pm$		
	Bq g ⁻¹	Bq g ⁻¹	Bq g ⁻¹	Bq g ⁻¹		
ABH004/02	1.979	0.030	2.41	0.133	21.78	3.16
ABH006/02	1.979	0.030	2.02	0.12	2.07	0.33
ABH016/02	1.979	0.030	2.0	0.2	1.06	0.10
ABH017/02	1.979	0.030	1.96	0.1	-0.96	0.18

Table 27 – Results for ^{238}Pu (high level)

Sample	NPL Data		Analyst Data			
					Deviation	u-test
					(%)	statistic
ABH***/02	^{238}Pu	$\pm$	^{238}Pu	$\pm$		
	Bq g ⁻¹	Bq g ⁻¹	Bq g ⁻¹	Bq g ⁻¹		
ABH003/02	2.000	0.016	1.971	0.055	-1.45	0.51
ABH004/02	2.000	0.016	1.71	0.177	-14.50	1.63
ABH006/02	2.000	0.016	2.02	0.04	1.00	0.46
ABH009/02	2.000	0.016	1.86	0.04	-7.00	3.25
ABH016/02a	2.000	0.016	1.88	0.06	-6.00	1.93
ABH016/02b	2.000	0.016	1.93	0.08	-3.50	0.86
ABH016/02c	2.000	0.016	1.98	0.07	-1.00	0.28
ABH017/02	2.000	0.016	1.9	0.04	-5.00	2.32

Table 28 – Results for ^{239}Pu (high level)

Sample	NPL Data		Analyst Data			
					Deviation	u-test
					(%)	statistic
ABH***/02	^{239}Pu	$\pm$	^{239}Pu	$\pm$		
	Bq g ⁻¹	Bq g ⁻¹	Bq g ⁻¹	Bq g ⁻¹		
ABH003/02	1.991	0.023	1.998	0.056	0.35	0.12
ABH004/02	1.991	0.023	1.88	0.188	-5.58	0.59
ABH006/02	1.991	0.023	2.00	0.04	0.45	0.20
ABH009/02	1.991	0.023	1.93	0.04	-3.06	1.32
ABH016/02a	1.991	0.023	1.92	0.07	-3.57	0.96
ABH016/02b	1.991	0.023	1.90	0.08	-4.57	1.09
ABH016/02c	1.991	0.023	1.97	0.07	-1.05	0.29
ABH017/02	1.991	0.023	1.89	0.04	-5.07	2.19

Table 29 – Results for ^{241}Am (high level)

Sample	NPL Data		Analyst Data			
					Deviation	u-test
					(%)	statistic
ABH***/02	^{241}Am	$\pm$	^{241}Am	$\pm$		
	Bq g^{-1}	Bq g^{-1}	Bq g^{-1}	Bq g^{-1}		
ABH003/02	1.996	0.018	1.758	0.055	-11.92	4.11
ABH004/02a	1.996	0.018	1.81	0.208	-9.32	0.89
ABH004/02b	1.996	0.018	1.91	0.0205	-4.31	3.15
ABH005/02	1.996	0.018	2.25	0.11	12.73	2.28
ABH006/02	1.996	0.018	1.85	0.05	-7.31	2.75
ABH009/02a	1.996	0.018	1.99	0.03	-0.30	0.17
ABH009/02b	1.996	0.018	2.06	0.06	3.21	1.02
ABH016/02a	1.996	0.018	1.92	0.08	-3.81	0.93
ABH016/02b	1.996	0.018	1.96	0.08	-1.80	0.44
ABH016/02c	1.996	0.018	2.06	0.08	3.21	0.78
ABH017/02	1.996	0.018	1.98	0.04	-0.80	0.36

Table 30 – Results for ^3H (low level)

Sample	NPL Data		Analyst Data			
					Deviation	u-test
					(%)	statistic
LBL***/02	^3H	$\pm$	^3H	$\pm$		
	Bq kg^{-1}	Bq kg^{-1}	Bq kg^{-1}	Bq kg^{-1}		
LBL002/02	25.13	0.56	26.53	2.25	5.57	0.60
LBL003/02	25.13	0.56	27.3	1.79	8.64	1.16
LBL007/02	25.13	0.56	27.6	4.6	9.83	0.53
LBL008/02	25.13	0.56	27.0	3.1	7.44	0.59
LBL009/02	25.13	0.56	21.5	3.5	-14.44	1.02
LBL010/02	25.13	0.56	23.7	1.9	-5.69	0.72

Table 31 – Results for ^{14}C (low level)

Sample	NPL Data		Analyst Data			
					Deviation	u-test
					(%)	statistic
LBL***/02	^{14}C	$\pm$	^{14}C	$\pm$		
	Bq kg^{-1}	Bq kg^{-1}	Bq kg^{-1}	Bq kg^{-1}		
LBL002/02	24.41	0.53	22.9	1.0	-6.19	1.33
LBL003/02	24.41	0.53	26.8	1.13	9.79	1.91
LBL007/02	24.41	0.53	26.1	3.7	6.92	0.45
LBL008/02	24.41	0.53	1.27	0.46	-94.80	32.97

Table 32 – Results for ^{35}S (low level)

Sample	NPL Data		Analyst Data			
					Deviation	u-test
					(%)	statistic
LBL***/02	^{35}S	$\pm$	^{35}S	$\pm$		
	Bq kg^{-1}	Bq kg^{-1}	Bq kg^{-1}	Bq kg^{-1}		
LBL003/02	25.36	0.55	24.6	2.71	-3.00	0.27
LBL007/02	25.36	0.55	26.6	1.6	4.89	0.73
LBL008/02	25.36	0.55	51.2	7.4	101.89	3.48

Table 33 – Results for ^3H (High level)

Sample	NPL Data		Analyst Data			
					Deviation	u-test
					(%)	statistic
LBH***02	^3H	$\pm$	^3H	$\pm$		
	Bq g ⁻¹	Bq g ⁻¹	Bq g ⁻¹	Bq g ⁻¹		
LBH002/02	20.04	0.18	16.753	0.282	-16.40	9.83
LBH003/02	20.04	0.18	20.4	1.15	1.80	0.31
LBH004/02a	20.04	0.18	20	1	-0.20	0.04
LBH004/02b	20.04	0.18	19	1	-5.19	1.02
LBH005/02	20.04	0.18	20.9	1	4.29	0.85
LBH006/02	20.04	0.18	20.44	0.67	2.00	0.58
LBH007/02	20.04	0.18	19.63	1.58	-2.05	0.26
LBH010/02	20.04	0.18	21.04	2.1	4.99	0.47
LBH011/02a	20.04	0.18	17.6	1.0	-12.18	2.40
LBH011/02b	20.04	0.18	19.9	1.1	-0.70	0.13
LBH011/02c	20.04	0.18	21.5	2.7	7.29	0.54
LBH012/02	20.04	0.18	22.69	0.075	13.22	13.59
LBH013/02a	20.04	0.18	20.78	0.36	3.69	1.84
LBH013/02b	20.04	0.18	19.52	0.30	-2.59	1.49
LBH013/02c	20.04	0.18	19.85	0.26	-0.95	0.60
LBH013/02d	20.04	0.18	19.76	0.32	-1.40	0.76
LBH015/02	20.04	0.18	19.5	1.03	-2.69	0.52

Table 34 – Results for ^{14}C (High level)

Sample	NPL Data		Analyst Data			
					Deviation	u-test
					(%)	statistic
LBH***02	^{14}C	$\pm$	^{14}C	$\pm$		
	Bq g ⁻¹	Bq g ⁻¹	Bq g ⁻¹	Bq g ⁻¹		
LBH003/02	19.46	0.12	22.2	0.873	14.08	3.11

Table 35 – Results for ^{35}S (High level)

Sample	NPL Data		Analyst Data			
					Deviation	u-test
					(%)	statistic
LBH***02	^{35}S	$\pm$	^{35}S	$\pm$		
	Bq g ⁻¹	Bq g ⁻¹	Bq g ⁻¹	Bq g ⁻¹		
LBH003/02	20.22	0.14	21.3	1.8	5.34	0.60
LBH005/02	20.22	0.14	19.9	0.7	-1.58	0.45
LBH007/02	20.22	0.14	11.18	1.51	-44.71	5.96

Table 36 – Results for ^{22}Na (low level)

Sample	NPL Data		Analyst Data			
					Deviation	u-test
					(%)	statistic
BGL***02	^{22}Na	$\pm$	^{22}Na	$\pm$		
	Bq kg ⁻¹	Bq kg ⁻¹	Bq kg ⁻¹	Bq kg ⁻¹		
BGL003/02	2.67	0.054	2.72	0.13	1.87	0.36
BGL004/02	2.67	0.054	2.33	0.742	-12.73	0.46
BGL005/02	2.67	0.054	2.08	0.608	-22.10	0.97
BGL007/02	2.67	0.054	3.39	0.22	26.97	3.18
BGL009/02	2.67	0.054	<5	-	-	-
BGL010&1 1/02	2.67	0.054	2.6	0.11	-2.62	0.57
BGL012/02	2.67	0.054	4.32	0.54	61.80	3.04
BGL013/02	2.67	0.054	2.68	0.47	0.37	0.02
BGL016/02	2.67	0.054	2.8	0.7	4.87	0.19
BGL019/02	2.67	0.054	2.95	0.24	10.49	1.14
BGL020/02	2.67	0.054	2.29	0.35	-14.23	1.07
BGL021/02	2.67	0.054	2.4	0.2	-10.11	1.30
BGL024/02	2.67	0.054	2.1	0.47	-21.35	1.20
BGL025/02	2.67	0.054	2.7	0.7	1.12	0.04
BGL026/02	2.67	0.054	2.45	0.3	-8.24	0.72
BGL027/02	2.67	0.054	3	0.5	12.36	0.66

Table 37 – Results for ^{57}Co (low level)

Sample	NPL Data		Analyst Data			
					Deviation	u-test
					(%)	statistic
BGL***/02	^{57}Co	$\pm$	^{57}Co	$\pm$		
	Bq kg ⁻¹	Bq kg ⁻¹	Bq kg ⁻¹	Bq kg ⁻¹		
BGL003/02	2.649	0.058	2.79	0.24	5.32	0.57
BGL004/02	2.649	0.058	5.02	1.6	89.51	1.48
BGL005/02	2.649	0.058	3.12	0.772	17.78	0.61
BGL007/02	2.649	0.058	2.68	0.15	1.17	0.19
BGL009/02	2.649	0.058	2.5	0.2	-5.62	0.72
BGL010& 11/02	2.649	0.058	2.36	0.1	-10.91	2.50
BGL012/02	2.649	0.058	2.44	0.2	-7.89	1.00
BGL013/02	2.649	0.058	2.24	0.22	-15.44	1.80
BGL016/02	2.649	0.058	2.7	0.2	1.93	0.24
BGL019/02	2.649	0.058	2.75	0.11	3.81	0.81
BGL020/02	2.649	0.058	2.45	0.28	-7.51	0.70
BGL021/02	2.649	0.058	2.7	0.15	1.93	0.32
BGL024/02	2.649	0.058	2.37	0.16	-10.53	1.64
BGL025/02	2.649	0.058	3.2	0.7	20.80	0.78
BGL026/02	2.649	0.058	2.68	0.13	1.17	0.22
BGL027/02	2.649	0.058	2.3	0.4	-13.17	0.86

Table 38 – Results for ^{60}Co (low level)

Sample	NPL Data		Analyst Data		Deviation	u-test
					(%)	statistic
BGL***/02	^{60}Co	$\pm$	^{60}Co	$\pm$		
	Bq kg^{-1}	Bq kg^{-1}	Bq kg^{-1}	Bq kg^{-1}		
BGL003/02	2.651	0.053	2.54	0.1	-4.19	0.98
BGL004/02	2.651	0.053	2.88	0.919	8.64	0.25
BGL005/02	2.651	0.053	2.77	0.19	4.49	0.60
BGL007/02	2.651	0.053	2.61	0.16	-1.55	0.24
BGL009/02	2.651	0.053	2.5	0.2	-5.70	0.73
BGL010& 11/02	2.651	0.053	2.65	0.12	-0.04	0.01
BGL012/02	2.651	0.053	3.17	0.31	19.58	1.65
BGL013/02	2.651	0.053	3.19	0.20	20.33	2.61
BGL016/02	2.651	0.053	2.8	0.8	5.62	0.19
BGL019/02	2.651	0.053	2.75	0.15	3.73	0.62
BGL020/02	2.651	0.053	2.44	0.20	-7.96	1.02
BGL021/02	2.651	0.053	2.6	0.15	-1.92	0.32
BGL024/02	2.651	0.053	2.08	0.13	-21.54	4.07
BGL025/02	2.651	0.053	2.81	0.19	6.00	0.81
BGL026/02	2.651	0.053	2.8	0.7	5.62	0.21
BGL027/02	2.651	0.053	2.7	0.2	1.85	0.24

Table 39 – Results for ^{95}Zr (low level)

Sample	NPL Data		Analyst Data			
					Deviation	u-test
					(%)	statistic
BGL***/02	^{95}Zr	$\pm$	^{95}Zr	$\pm$		
	Bq kg^{-1}	Bq kg^{-1}	Bq kg^{-1}	Bq kg^{-1}		
BGL003/02	2.564	0.066	2.34	0.23	-8.74	0.94
BGL004/02	2.564	0.066	8.32	2.65	224.49	2.17
BGL005/02	2.564	0.066	1.83	0.929	-28.63	0.79
BGL007/02	2.564	0.066	1.81	0.12	-29.41	5.51
BGL009/02	2.564	0.066	3.5	0.6	36.51	1.55
BGL010& 11/02	2.564	0.066	3.25	0.26	26.76	2.56
BGL016/02	2.564	0.066	3.3	0.9	28.71	0.82
BGL019/02	2.564	0.066	2.41	0.25	-6.01	0.60
BGL020/02	2.564	0.066	<4	-	-	-
BGL021/02	2.564	0.066	2.5	0.4	-2.50	0.16
BGL024/02	2.564	0.066	2.78	0.19	8.42	1.07
BGL025/02	2.564	0.066	1.6	0.2	-37.60	4.58
BGL026/02	2.564	0.066	2.49	0.61	-2.89	0.12
BGL027/02	2.564	0.066	3.1	0.4	20.90	1.32

Table 40 – Results for ^{106}Ru (low level)

Sample	NPL Data		Analyst Data			
					Deviation	u-test
					(%)	statistic
BGL***/02	^{106}Ru	$\pm$	^{106}Ru	$\pm$		
	Bq kg^{-1}	Bq kg^{-1}	Bq kg^{-1}	Bq kg^{-1}		
BGL003/02	2.654	0.054	2.55	0.41	-3.92	0.25
BGL005/02	2.654	0.054	3.43	0.463	29.24	1.66
BGL007/02	2.654	0.054	2.18	0.95	-17.86	0.50
BGL009/02	2.654	0.054	<5	-	-	-
BGL010& 11/02	2.654	0.054	2.49	0.75	-6.18	0.22
BGL016/02	2.654	0.054	2.9	1.7	9.27	0.14
BGL019/02	2.654	0.054	2.8	1.2	5.50	0.12
BGL020/02	2.654	0.054	<10	-	-	-
BGL026/02	2.654	0.054	2.09	0.59	-21.25	0.95

Table 41 – Results for ^{134}Cs (low level)

Sample	NPL Data		Analyst Data		Deviation	u-test
					(%)	statistic
BGL***/02	^{134}Cs	$\pm$	^{134}Cs	$\pm$		
	Bq kg ⁻¹	Bq kg ⁻¹	Bq kg ⁻¹	Bq kg ⁻¹		
BGL003/02	2.672	0.056	2.57	0.11	-3.82	0.83
BGL004/02	2.672	0.056	2.71	0.865	1.42	0.04
BGL005/02	2.672	0.056	2.67	0.0757	-0.07	0.02
BGL007/02	2.672	0.056	2.37	0.14	-11.30	2.00
BGL009/02	2.672	0.056	2.4	0.2	-10.18	1.31
BGL010& 11/02	2.672	0.056	2.47	0.1	-7.56	1.76
BGL012/02	2.672	0.056	2.64	0.22	-1.20	0.14
BGL013/02	2.672	0.056	2.59	0.20	-3.07	0.39
BGL016/02	2.672	0.056	2.6	0.4	-2.69	0.18
BGL019/02	2.672	0.056	2.766	0.076	3.52	1.00
BGL020/02	2.672	0.056	2.14	0.2	-19.91	2.56
BGL021/02	2.672	0.056	2.5	0.15	-6.44	1.07
BGL024/02	2.672	0.056	2.16	0.14	-19.16	3.40
BGL025/02	2.672	0.056	2.7	0.7	1.05	0.04
BGL026/02	2.672	0.056	2.56	0.14	-4.19	0.74
BGL027/02	2.672	0.056	2.8	0.2	4.79	0.62

Table 42 – Results for ^{137}Cs (low level)

Sample	NPL Data		Analyst Data			
					Deviation	u-test
					(%)	statistic
BGL***/02	^{137}Cs	$\pm$	^{137}Cs	$\pm$		
	Bq kg^{-1}	Bq kg^{-1}	Bq kg^{-1}	Bq kg^{-1}		
BGL003/02	2.659	0.056	2.67	0.1	0.41	0.10
BGL004/02	2.659	0.056	3.04	0.969	14.33	0.39
BGL005/02	2.659	0.056	2.48	0.18	-6.73	0.95
BGL007/02	2.659	0.056	2.96	0.19	11.32	1.52
BGL009/02	2.659	0.056	2.8	0.2	5.30	0.68
BGL010& 11/02	2.659	0.056	2.71	0.13	1.92	0.36
BGL012/02	2.659	0.056	2.85	0.23	7.18	0.81
BGL013/02	2.659	0.056	2.63	0.49	-1.09	0.06
BGL016/02	2.659	0.056	2.8	0.5	5.30	0.28
BGL019/02	2.659	0.056	2.8	0.16	5.30	0.83
BGL020/02	2.659	0.056	2.54	0.25	-4.48	0.46
BGL021/02	2.659	0.056	2.7	0.15	1.54	0.26
BGL024/02	2.659	0.056	2.72	0.3	2.29	0.20
BGL025/02	2.659	0.056	2.7	0.6	1.54	0.07
BGL026/02	2.659	0.056	2.75	0.2	3.42	0.44
BGL027/02	2.659	0.056	2.9	0.2	9.06	1.16

Table 43 – Results for ^{154}Eu (low level)

Sample	NPL Data		Analyst Data		Deviation	u-test
					(%)	statistic
BGL***/02	^{154}Eu	$\pm$	^{154}Eu	$\pm$		
	Bq kg ⁻¹	Bq kg ⁻¹	Bq kg ⁻¹	Bq kg ⁻¹		
BGL003/02	2.745	0.058	2.63	0.23	-4.19	0.48
BGL004/02	2.745	0.058	3.32	1.06	20.95	0.54
BGL005/02	2.745	0.058	3.66	1.18	33.33	0.77
BGL007/02	2.745	0.058	3.25	0.58	18.40	0.87
BGL009/02	2.745	0.058	2.4	0.3	-12.57	1.13
BGL010& 11/02	2.745	0.058	2.58	0.35	-6.01	0.47
BGL012/02	2.745	0.058	2.62	0.32	-4.55	0.38
BGL013/02	2.745	0.058	2.29	0.30	-16.58	1.49
BGL016/02	2.745	0.058	3.3	0.5	20.22	1.10
BGL019/02	2.745	0.058	2.72	0.18	-0.91	0.13
BGL020/02	2.745	0.058	2.35	0.69	-14.39	0.57
BGL021/02	2.745	0.058	2.6	0.15	-5.28	0.90
BGL024/02	2.745	0.058	2.31	0.49	-15.85	0.88
BGL025/02	2.745	0.058	3.7	1.3	34.79	0.73
BGL026/02	2.745	0.058	2.66	0.18	-3.10	0.45
BGL027/02	2.745	0.058	2.5	0.5	-8.93	0.49

Table 44 – Results for ^{155}Eu (low level)

Sample	NPL Data		Analyst Data		Deviation	u-test
					(%)	statistic
BGL***/02	^{155}Eu	$\pm$	^{155}Eu	$\pm$		
	Bq kg^{-1}	Bq kg^{-1}	Bq kg^{-1}	Bq kg^{-1}		
BGL003/02	2.693	0.062	2.74	0.14	1.75	0.31
BGL004/02	2.693	0.062	2.74	0.874	1.75	0.05
BGL005/02	2.693	0.062	3.53	0.508	31.08	1.64
BGL007/02	2.693	0.062	3.03	0.2	12.51	1.61
BGL009/02	2.693	0.062	3.2	0.4	18.83	1.25
BGL010& 11/02	2.693	0.062	2.23	0.16	-17.19	2.70
BGL012/02	2.693	0.062	2.72	0.3	1.00	0.09
BGL013/02	2.693	0.062	4.42	0.71	64.13	2.42
BGL016/02	2.693	0.062	2.9	0.6	7.69	0.34
BGL019/02	2.693	0.062	2.925	0.066	8.61	2.56
BGL020/02	2.693	0.062	<2	-	-	-
BGL021/02	2.693	0.062	2.7	0.2	0.26	0.03
BGL024/02	2.693	0.062	2.2	0.47	-18.31	1.04
BGL025/02	2.693	0.062	2.4	0.6	-10.88	0.49
BGL026/02	2.693	0.062	2.45	0.44	-9.02	0.55
BGL027/02	2.693	0.062	2.7	0.3	0.26	0.02

Table 45 – Results for ^{22}Na (high level)

Sample	NPL Data		Analyst Data			
					Deviation	u-test
					(%)	statistic
BGH***/02	^{22}Na	$\pm$	^{22}Na	$\pm$		
	Bq g^{-1}	Bq g^{-1}	Bq g^{-1}	Bq g^{-1}		
BGH003/02	2.024	0.010	2.2	0.703	8.70	0.25
BGH004/02	2.024	0.010	2.336	0.0268	15.42	10.91
BGH005/02	2.024	0.010	1.85	0.111	-8.60	1.56
BGH007/02	2.024	0.010	2.54	0.13	25.49	3.96
BGH009/02	2.024	0.010	1.95	0.07	-3.66	1.05
BGH010/02	2.024	0.010	2.00	0.10	-1.19	0.24
BGH011/02	2.024	0.010	2.41	0.08	19.07	4.79
BGH012/02	2.024	0.010	1.60	0.12	-20.95	3.52
BGH014/02	2.024	0.010	1.06	0.10	-47.63	9.59
BGH017/02	2.024	0.010	2.05	0.21	1.28	0.12
BGH018/02	2.024	0.010	1.72	0.09	-15.02	3.36
BGH019/02	2.024	0.010	1.90	0.08	-6.13	1.54
BGH020/02	2.024	0.010	2.16	0.11	6.72	1.23
BGH024/02	2.024	0.010	1.9842	0.1159	-1.97	0.34
BGH027/02a	2.024	0.010	1.591	0.067	-21.39	6.39
BGH027/02b	2.024	0.010	1.726	0.050	-14.72	5.84
BGH027/02c	2.024	0.010	1.740	0.056	-14.03	4.99
BGH027/02d	2.024	0.010	1.605	0.106	-20.70	3.94
BGH030/02	2.024	0.010	1.99	0.10	-1.68	0.34

Table 46 – Results for ^{57}Co (high level)

Sample	NPL Data		Analyst Data			
					Deviation	u-test
					(%)	statistic
BGH***/02	^{57}Co	$\pm$	^{57}Co	$\pm$		
	Bq g ⁻¹	Bq g ⁻¹	Bq g ⁻¹	Bq g ⁻¹		
BGH003/02	2.008	0.020	2.23	0.721	11.06	0.31
BGH004/02	2.008	0.020	2.083	0.0420	3.74	1.61
BGH005/02	2.008	0.020	2.01	0.0698	0.10	0.03
BGH007/02	2.008	0.020	2.08	0.10	3.59	0.71
BGH009/02	2.008	0.020	1.99	0.06	-0.90	0.28
BGH010/02	2.008	0.020	1.98	0.10	-1.39	0.27
BGH011/02	2.008	0.020	1.96	0.06	-2.39	0.76
BGH012/02	2.008	0.020	2.10	0.14	4.58	0.65
BGH014/02	2.008	0.020	1.99	0.19	-0.90	0.09
BGH017/02	2.008	0.020	2.02	0.20	0.60	0.06
BGH018/02	2.008	0.020	1.81	0.09	-9.86	2.15
BGH019/02	2.008	0.020	1.80	0.07	-10.36	2.86
BGH020/02	2.008	0.020	2.29	0.10	14.04	2.77
BGH024/02	2.008	0.020	1.9786	0.1148	-1.46	0.25
BGH027/02a	2.008	0.020	1.969	0.026	-1.94	1.19
BGH027/02b	2.008	0.020	2.022	0.052	0.70	0.25
BGH027/02c	2.008	0.020	2.040	0.053	1.59	0.56
BGH027/02d	2.008	0.020	1.858	0.062	-7.47	2.30
BGH030/02	2.008	0.020	2.13	0.21	6.08	0.58

Table 47 – Results for ^{60}Co (high level)

Sample	NPL Data		Analyst Data		Deviation	u-test
					(%)	statistic
BGH***/02	^{60}Co	$\pm$	^{60}Co	$\pm$		
	Bq g ⁻¹	Bq g ⁻¹	Bq g ⁻¹	Bq g ⁻¹		
BGH003/02	2.009	0.008	2.23	0.713	11.00	0.31
BGH004/02	2.009	0.008	1.919	0.0233	-4.48	3.65
BGH005/02	2.009	0.008	2.00	0.0664	-0.45	0.13
BGH007/02	2.009	0.008	2.00	0.10	-0.45	0.09
BGH009/02	2.009	0.008	1.97	0.06	-1.94	0.64
BGH010/02	2.009	0.008	2.01	0.09	0.05	0.01
BGH011/02	2.009	0.008	1.93	0.05	-3.93	1.56
BGH012/02	2.009	0.008	1.94	0.02	-3.43	3.20
BGH014/02	2.009	0.008	2.16	0.21	7.52	0.72
BGH017/02	2.009	0.008	2.04	0.20	1.54	0.15
BGH018/02	2.009	0.008	1.82	0.09	-9.41	2.09
BGH019/02	2.009	0.008	2.00	0.06	-0.45	0.15
BGH020/02	2.009	0.008	2.22	0.11	10.50	1.91
BGH024/02	2.009	0.008	1.9949	0.1156	-0.70	0.12
BGH027/02a	2.009	0.008	1.910	0.026	-4.93	3.64
BGH027/02b	2.009	0.008	1.850	0.047	-7.91	3.34
BGH027/02c	2.009	0.008	1.850	0.049	-7.91	3.20
BGH027/02d	2.009	0.008	1.914	0.063	-4.73	1.50
BGH030/02	2.009	0.008	2.08	0.10	3.53	0.71

Table 48 – Results for ^{95}Zr (high level)

Sample	NPL Data		Analyst Data			
					Deviation	u-test
					(%)	statistic
BGH***/02	^{95}Zr	$\pm$	^{95}Zr	$\pm$		
	Bq g ⁻¹	Bq g ⁻¹	Bq g ⁻¹	Bq g ⁻¹		
BGH003/02	1.943	0.032	4.4	1.4	126.45	1.75
BGH004/02	1.943	0.032	1.812	0.0623	-6.74	1.87
BGH005/02	1.943	0.032	1.94	0.101	-0.15	0.03
BGH007/02	1.943	0.032	1.24	0.06	-36.18	10.34
BGH009/02	1.943	0.032	1.89	0.12	-2.73	0.43
BGH010/02	1.943	0.032	1.90	0.12	-2.21	0.35
BGH011/02	1.943	0.032	2.47	0.06	27.12	7.75
BGH012/02	1.943	0.032	2.23	0.20	14.77	1.42
BGH014/02	1.943	0.032	2.48	0.25	27.64	2.13
BGH017/02	1.943	0.032	2.06	0.21	6.02	0.55
BGH018/02	1.943	0.032	1.69	0.09	-13.02	2.65
BGH019/02	1.943	0.032	1.80	0.11	-7.36	1.25
BGH020/02	1.943	0.032	2.23	0.13	14.77	2.14
BGH024/02	1.943	0.032	1.7983	0.1335	-7.45	1.05
BGH027/02a	1.943	0.032	1.650	0.065	-15.08	4.04
BGH027/02b	1.943	0.032	2.367	0.063	21.82	6.00
BGH027/02c	1.943	0.032	1.870	0.091	-3.76	0.76
BGH027/02d	1.943	0.032	1.785	0.137	-8.13	1.12
BGH030/02	1.943	0.032	1.89	0.09	-2.73	0.55

Table 49 – Results for ^{106}Ru (high level)

Sample	NPL Data		Analyst Data		Deviation	u-test
					(%)	statistic
BGH***/02	^{106}Ru	$\pm$	^{106}Ru	$\pm$		
	Bq g ⁻¹	Bq g ⁻¹	Bq g ⁻¹	Bq g ⁻¹		
BGH003/02	2.012	0.011	1.93	0.615	-4.08	0.13
BGH004/02	2.012	0.011	1.464	0.0526	-27.24	10.20
BGH005/02	2.012	0.011	1.95	0.142	-3.08	0.44
BGH007/02	2.012	0.011	1.75	0.09	-13.02	2.89
BGH009/02	2.012	0.011	1.92	0.18	-4.57	0.51
BGH010/02	2.012	0.011	1.99	0.10	-1.09	0.22
BGH011/02	2.012	0.011	1.79	0.06	-11.03	3.64
BGH012/02	2.012	0.011	1.74	0.10	-13.52	2.70
BGH014/02	2.012	0.011	4.27	0.42	112.23	5.37
BGH017/02	2.012	0.011	2.29	0.23	13.82	1.21
BGH018/02	2.012	0.011	1.65	0.17	-17.99	2.12
BGH019/02	2.012	0.011	1.60	0.18	-20.48	2.28
BGH024/02	2.012	0.011	1.7581	0.1305	-12.62	1.94
BGH027/02a	2.012	0.011	1.808	0.027	-10.14	7.00
BGH027/02b	2.012	0.011	1.692	0.049	-15.90	6.37
BGH027/02c	2.012	0.011	1.630	0.054	-18.99	6.93
BGH027/02d	2.012	0.011	1.715	0.074	-14.76	3.97
BGH030/02	2.012	0.011	1.95	0.11	-3.08	0.56

Table 50 – Results for ^{134}Cs (high level)

Sample	NPL Data		Analyst Data			
					Deviation	u-test
					(%)	statistic
BGH***/02	^{134}Cs	$\pm$	^{134}Cs	$\pm$		
	Bq g^{-1}	Bq g^{-1}	Bq g^{-1}	Bq g^{-1}		
BGH003/02	2.025	0.016	2.05	0.654	1.23	0.04
BGH004/02	2.025	0.016	1.642	0.0200	-18.91	14.95
BGH005/02	2.025	0.016	2.00	0.0494	-1.23	0.48
BGH007/02	2.025	0.016	1.79	0.09	-11.60	2.57
BGH009/02	2.025	0.016	1.90	0.06	-6.17	2.01
BGH010/02	2.025	0.016	1.97	0.08	-2.72	0.67
BGH011/02	2.025	0.016	1.81	0.06	-10.62	3.46
BGH012/02	2.025	0.016	1.73	0.07	-14.57	4.11
BGH014/02	2.025	0.016	1.75	0.17	-13.58	1.61
BGH017/02	2.025	0.016	2.29	0.23	13.09	1.15
BGH018/02	2.025	0.016	1.59	0.12	-21.48	3.59
BGH019/02	2.025	0.016	1.80	0.06	-11.11	3.62
BGH020/02	2.025	0.016	2.01	0.23	-0.74	0.07
BGH024/02	2.025	0.016	1.9075	0.1105	-5.80	1.05
BGH027/02a	2.025	0.016	1.820	0.025	-10.12	6.91
BGH027/02b	2.025	0.016	1.744	0.045	-13.88	5.88
BGH027/02c	2.025	0.016	1.710	0.045	-15.56	6.60
BGH027/02d	2.025	0.016	1.690	0.056	-16.54	5.75
BGH030/02	2.025	0.016	1.95	0.10	-3.70	0.74

Table 51 – Results for ^{137}Cs (high level)

Sample	NPL Data		Analyst Data			
					Deviation	u-test
					(%)	statistic
BGH***/02	^{137}Cs	$\pm$	^{137}Cs	$\pm$		
	Bq g^{-1}	Bq g^{-1}	Bq g^{-1}	Bq g^{-1}		
BGH003/02	2.015	0.015	2.30	0.734	14.14	0.39
BGH004/02	2.015	0.015	1.900	0.0237	-5.71	4.10
BGH005/02	2.015	0.015	1.97	0.0396	-2.23	1.06
BGH007/02	2.015	0.015	2.14	0.11	6.20	1.13
BGH009/02	2.015	0.015	1.98	0.06	-1.74	0.57
BGH010/02	2.015	0.015	2.00	0.09	-0.74	0.16
BGH011/02	2.015	0.015	2.01	0.06	-0.25	0.08
BGH012/02	2.015	0.015	2.07	0.03	2.73	1.64
BGH014/02	2.015	0.015	2.07	0.20	2.73	0.27
BGH017/02	2.015	0.015	2.07	0.21	2.73	0.26
BGH018/02	2.015	0.015	1.85	0.08	-8.19	2.03
BGH019/02	2.015	0.015	1.90	0.06	-5.71	1.86
BGH020/02	2.015	0.015	2.25	0.12	11.66	1.94
BGH024/02	2.015	0.015	1.9493	0.1133	-3.26	0.57
BGH027/02a	2.015	0.015	2.101	0.028	4.27	2.71
BGH027/02b	2.015	0.015	1.952	0.050	-3.13	1.21
BGH027/02c	2.015	0.015	1.900	0.050	-5.71	2.20
BGH027/02d	2.015	0.015	1.997	0.066	-0.89	0.27
BGH030/02	2.015	0.015	2.17	0.11	7.69	1.40

Table 52 – Results for ^{154}Eu (high level)

Sample	NPL Data		Analyst Data			
					Deviation	u-test
					(%)	statistic
BGH***/02	^{154}Eu	$\pm$	^{154}Eu	$\pm$		
	Bq g ⁻¹	Bq g ⁻¹	Bq g ⁻¹	Bq g ⁻¹		
BGH003/02	2.081	0.017	2.17	0.691	4.28	0.13
BGH004/02	2.081	0.017	1.823	0.0418	-12.40	5.72
BGH005/02	2.081	0.017	2.07	0.165	-0.53	0.07
BGH007/02	2.081	0.017	2.52	0.43	21.10	1.02
BGH009/02	2.081	0.017	1.92	0.06	-7.74	2.58
BGH010/02	2.081	0.017	2.08	0.1	-0.05	0.01
BGH011/02	2.081	0.017	1.84	0.06	-11.58	3.86
BGH012/02	2.081	0.017	2.01	0.08	-3.41	0.87
BGH014/02	2.081	0.017	1.93	0.18	-7.26	0.84
BGH017/02	2.081	0.017	2.28	0.23	9.56	0.86
BGH018/02	2.081	0.017	1.69	0.09	-18.79	4.27
BGH019/02	2.081	0.017	1.8	0.07	-13.50	3.90
BGH020/02	2.081	0.017	2.04	0.17	-1.97	0.24
BGH024/02	2.081	0.017	2.0075	0.1166	-3.53	0.62
BGH027/02a	2.081	0.017	1.963	0.02	-5.67	4.50
BGH027/02b	2.081	0.017	1.912	0.062	-8.12	2.63
BGH027/02c	2.081	0.017	1.75	0.047	-15.91	6.62
BGH027/02d	2.081	0.017	1.908	0.071	-8.31	2.37
BGH030/02	2.081	0.017	1.99	0.1	-4.37	0.90

Table 53 – Results for ^{155}Eu (high level)

Sample	NPL Data		Analyst Data			
					Deviation	u-test
					(%)	statistic
BGH***/02	^{155}Eu	$\pm$	^{155}Eu	$\pm$		
	Bq g ⁻¹	Bq g ⁻¹	Bq g ⁻¹	Bq g ⁻¹		
BGH003/02	2.041	0.024	2.19	0.699	7.30	0.21
BGH004/02	2.041	0.024	1.932	0.0582	-5.34	1.73
BGH005/02	2.041	0.024	2.03	0.0914	-0.54	0.12
BGH007/02	2.041	0.024	2.09	0.11	2.40	0.44
BGH009/02	2.041	0.024	2.01	0.15	-1.52	0.20
BGH010/02	2.041	0.024	2.06	0.09	0.93	0.20
BGH011/02	2.041	0.024	1.9	0.06	-6.91	2.18
BGH012/02	2.041	0.024	2.08	0.1	1.91	0.38
BGH014/02	2.041	0.024	1.96	0.19	-3.97	0.42
BGH017/02	2.041	0.024	2.11	0.21	3.38	0.33
BGH018/02	2.041	0.024	1.87	0.09	-8.38	1.84
BGH019/02	2.041	0.024	1.8	0.15	-11.81	1.59
BGH020/02	2.041	0.024	2.45	0.13	20.04	3.09
BGH024/02	2.041	0.024	1.9958	0.1207	-2.21	0.37
BGH027/02a	2.041	0.024	2.091	0.028	2.45	1.36
BGH027/02b	2.041	0.024	1.949	0.045	-4.51	1.80
BGH027/02c	2.041	0.024	1.87	0.045	-8.38	3.35
BGH027/02d	2.041	0.024	1.887	0.062	-7.55	2.32
BGH030/02	2.041	0.024	2.03	0.21	-0.54	0.05

Table 54 – Other reported radionuclides

Sample Identifier	Radionuclide	Reported activity concentration	Overall uncertainty
ABL22/02	Gross α measurement	2.43 Bq/kg	2 %
ABL22/02	Gross β measurement	37 Bq/kg	1 %
BGL004/02	^{124}Sb	9.39 Bq/kg	2.99 Bq/kg
BGL012/02	^{170}Tm	2.80 Bq/kg	0.68 Bq/kg

Figure 1 - Reported ^{90}Sr results (low level)

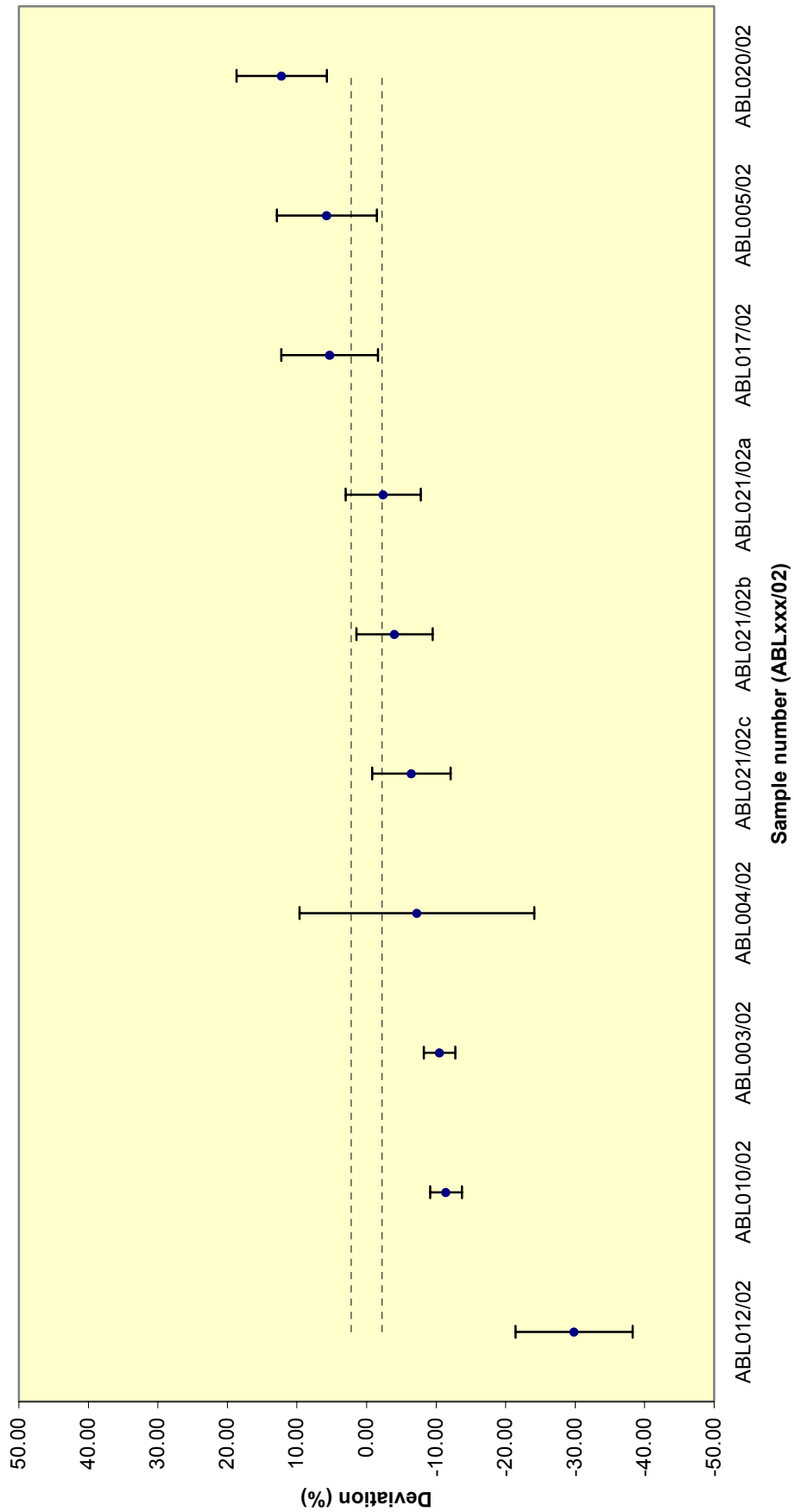


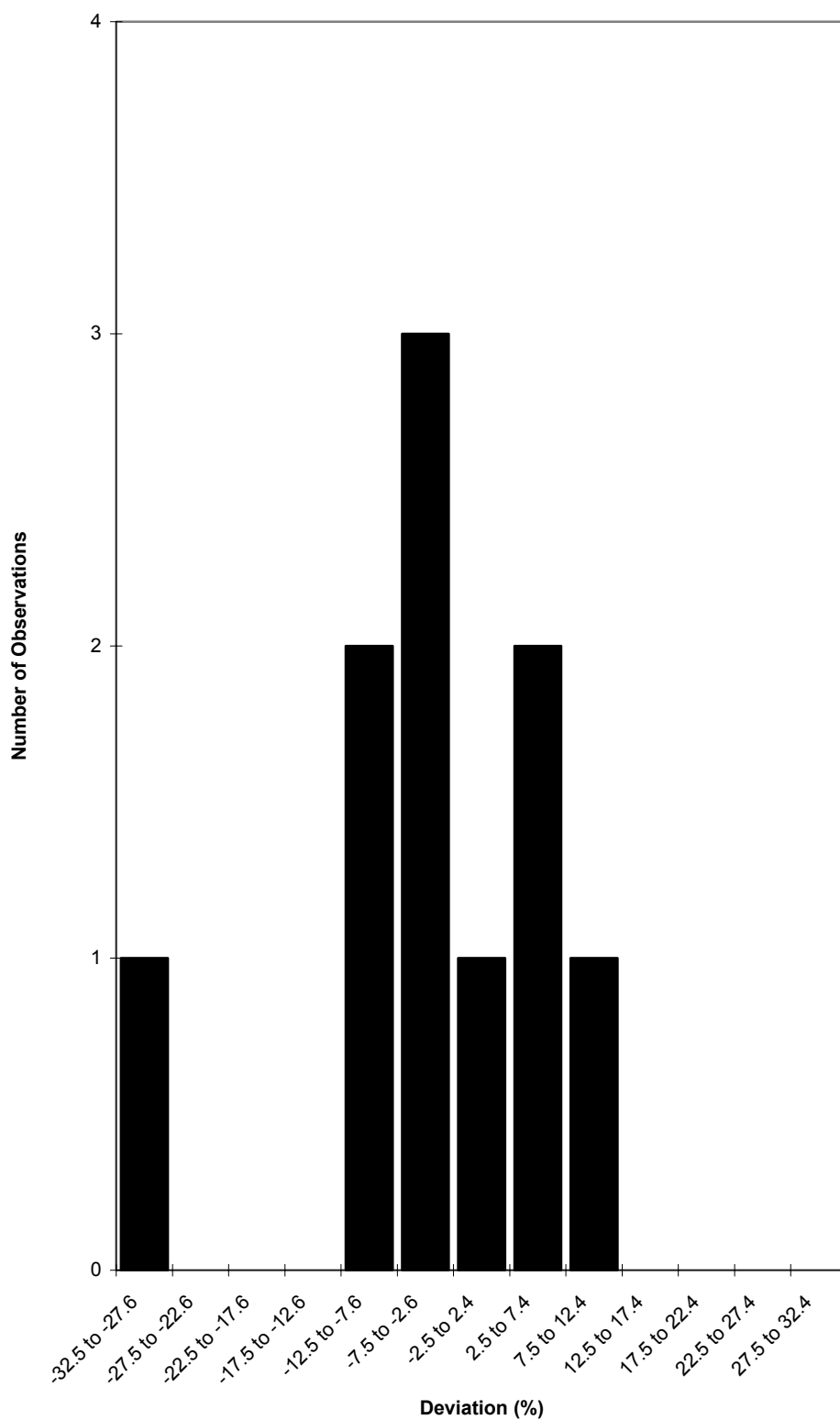
Figure 2 ^{90}Sr low level results

Figure 3 - Reported ^{210}Pb results (low level)

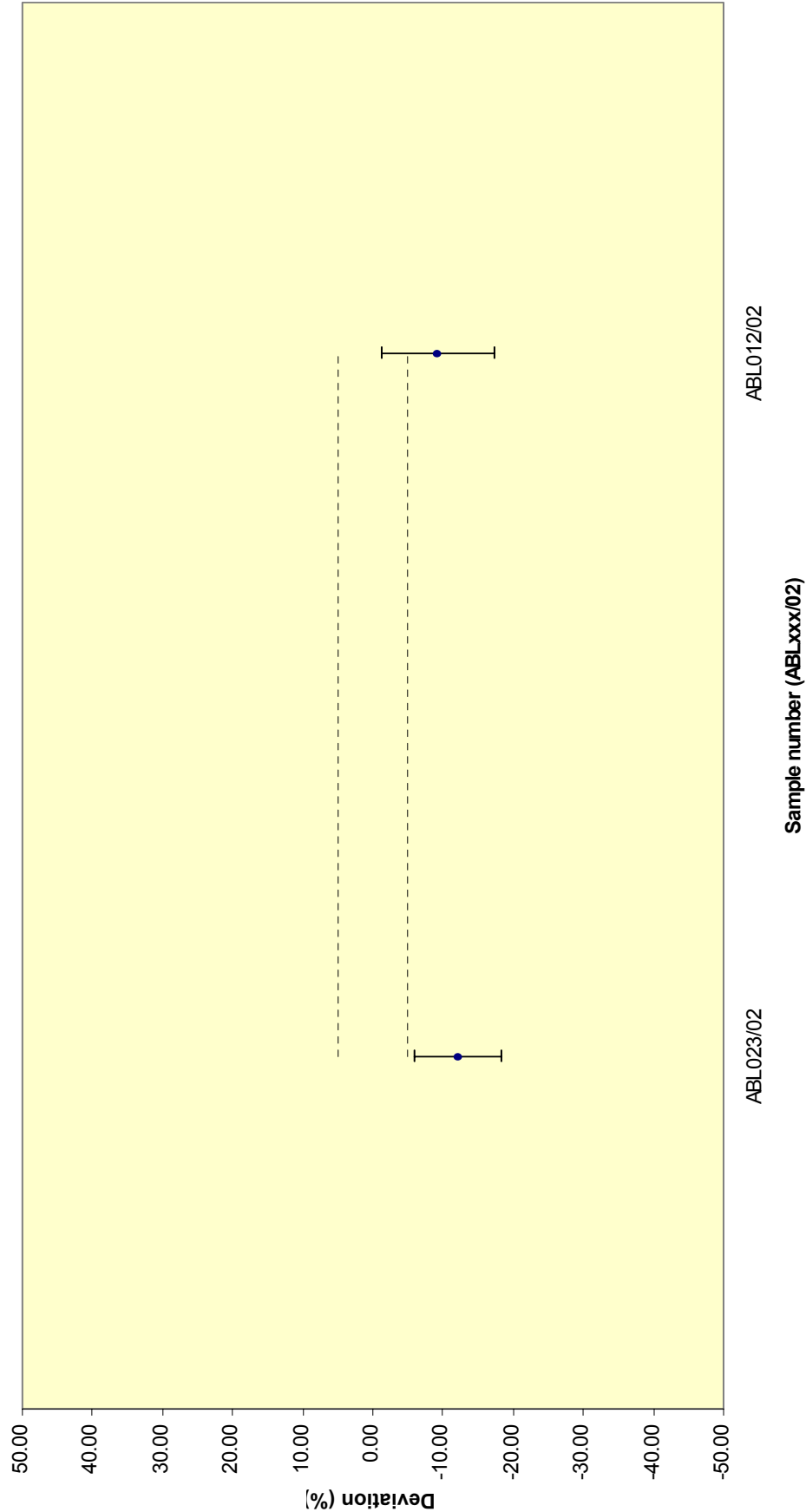


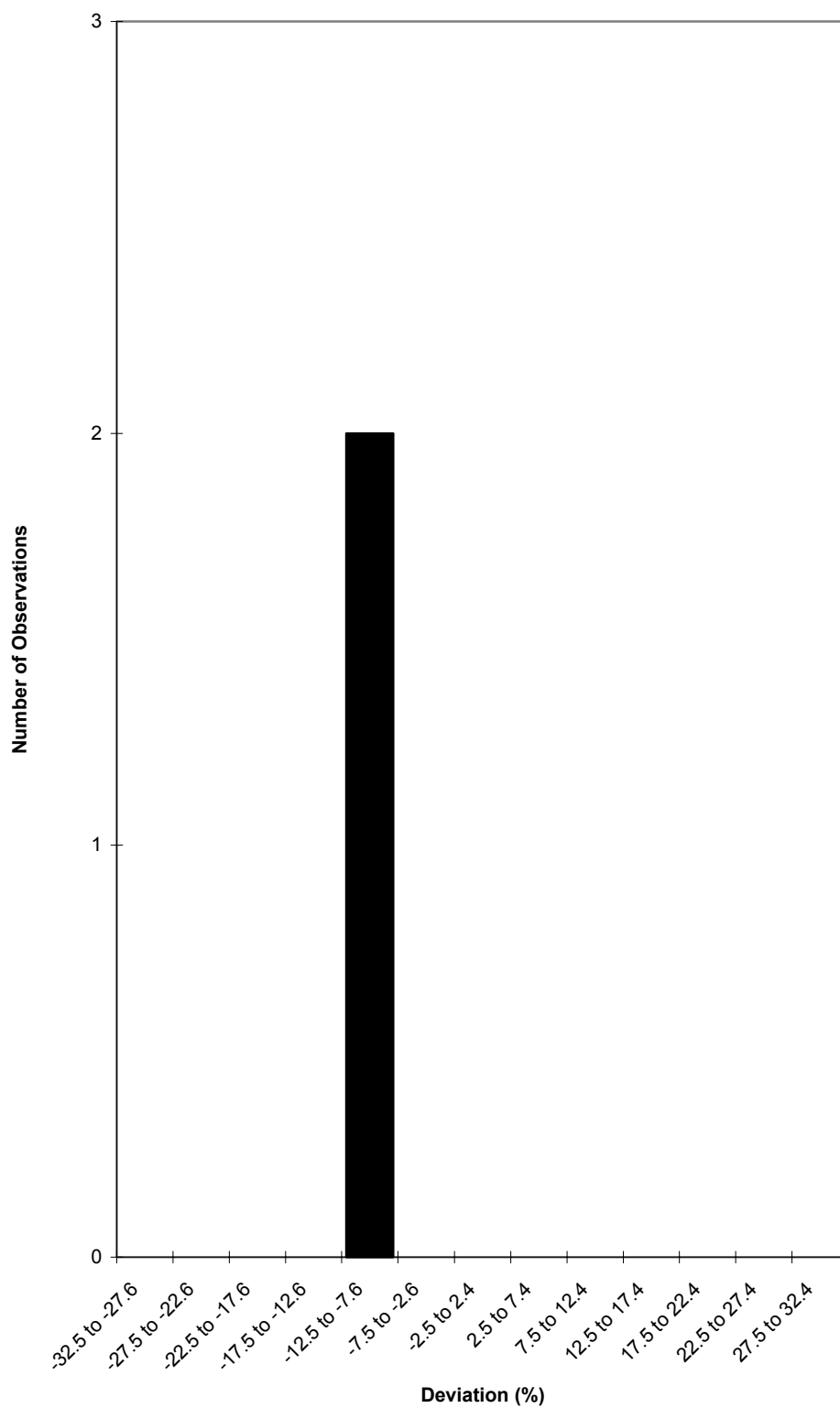
Figure 4 ^{210}Pb low level results

Figure 5 - Reported ^{226}Ra results (low level)

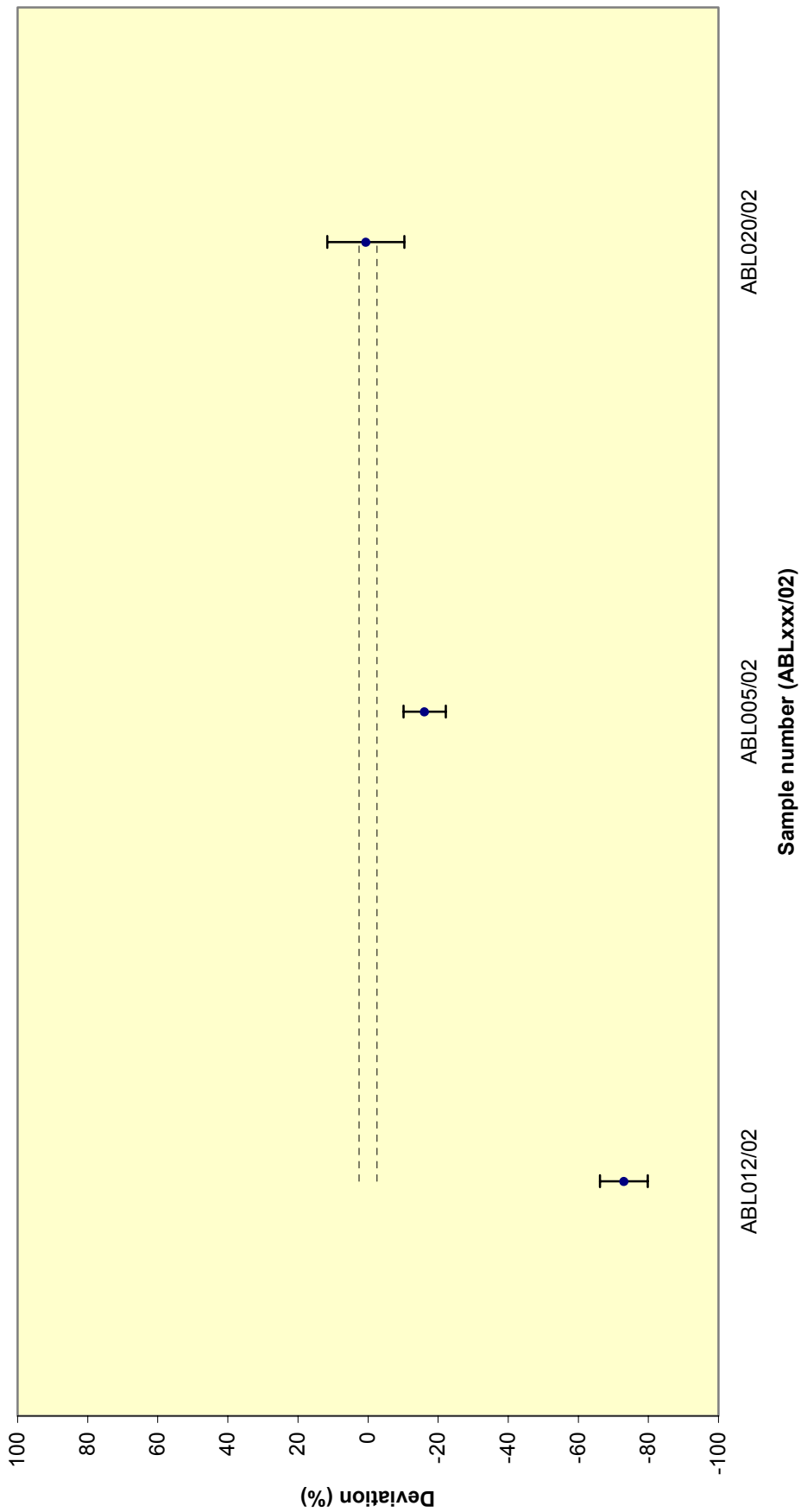


Figure 6 ^{226}Ra low level results
(one outside limits of plot)

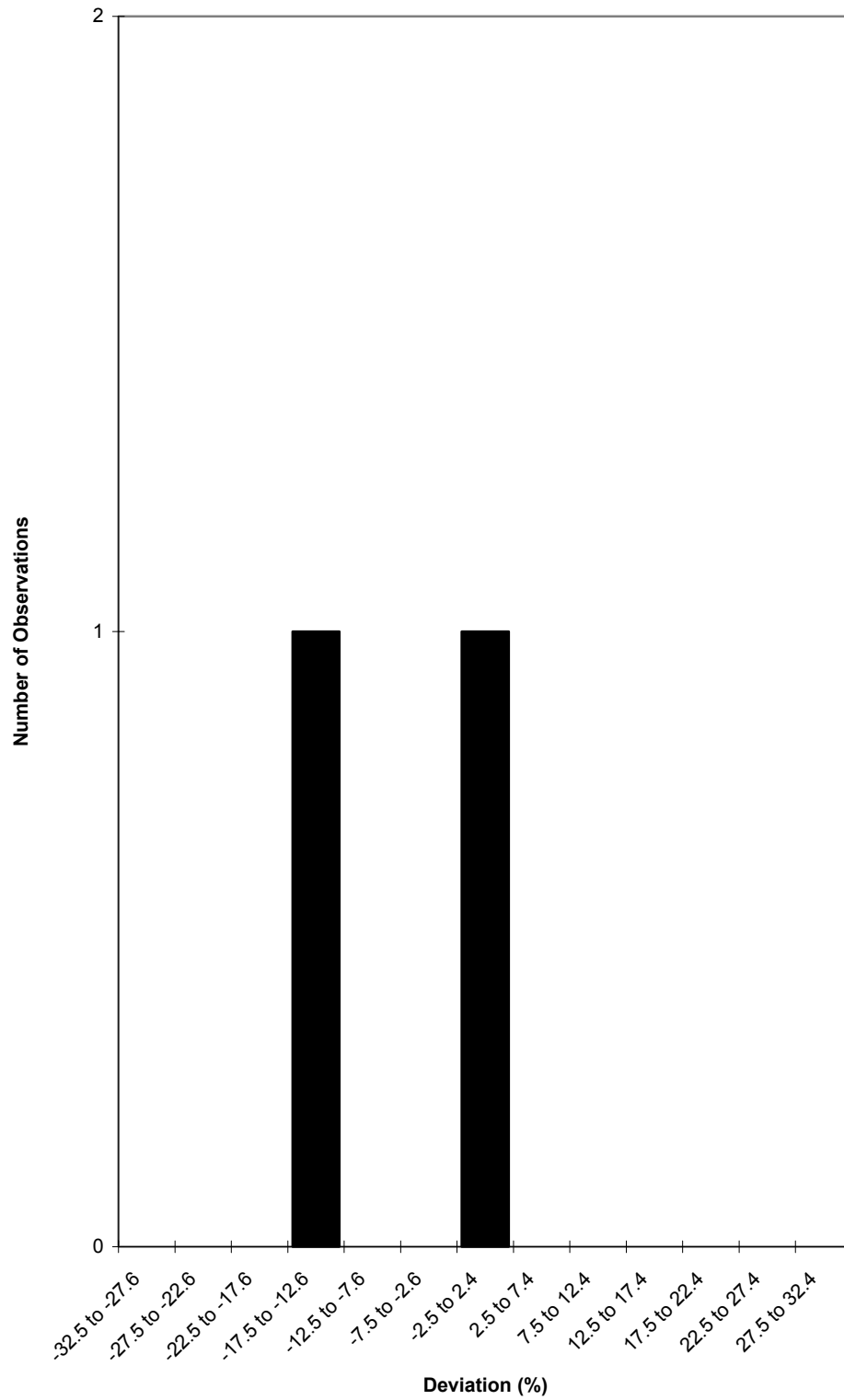


Figure 7 - Reported ^{238}Pu results (low level)

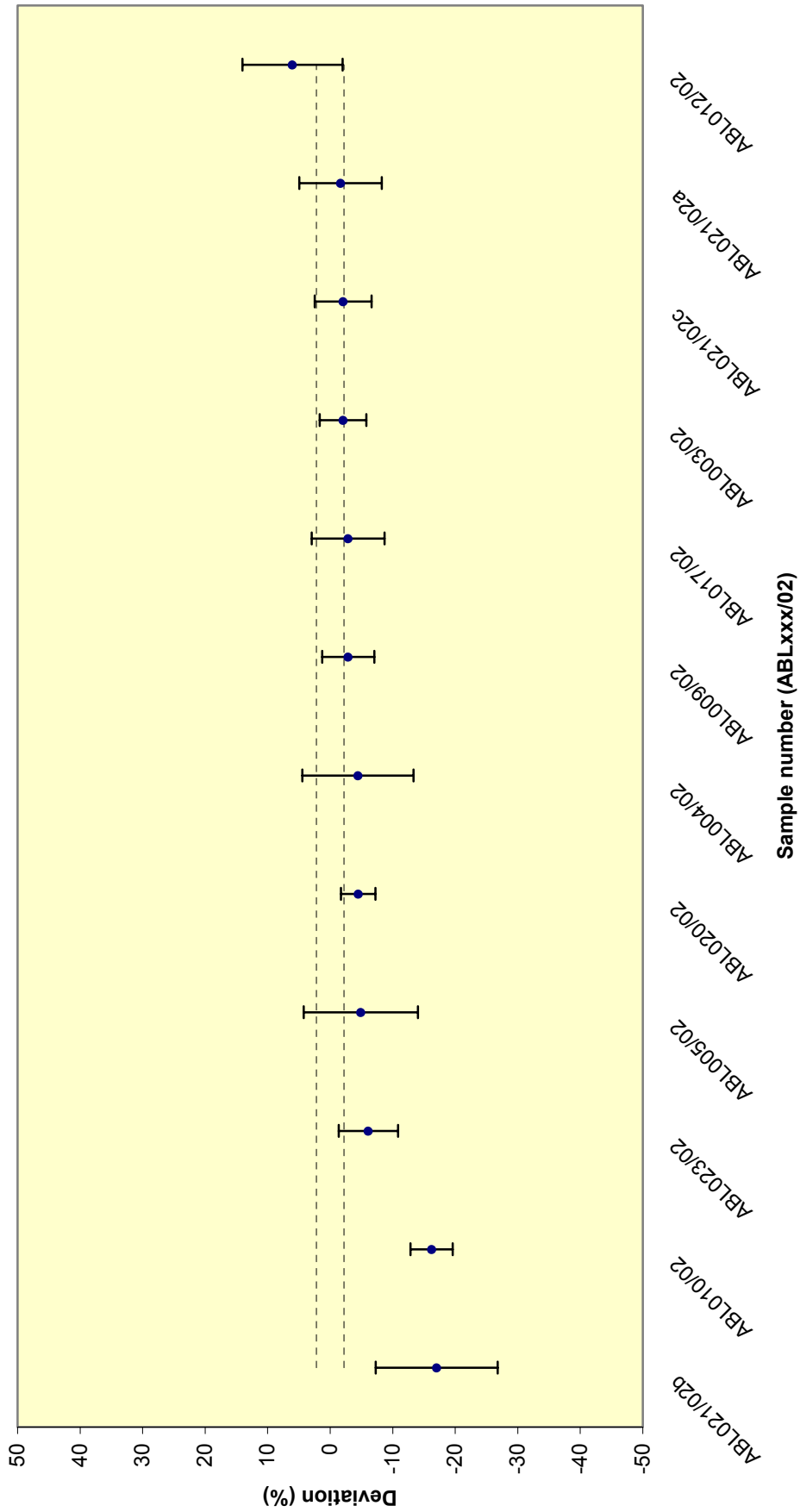


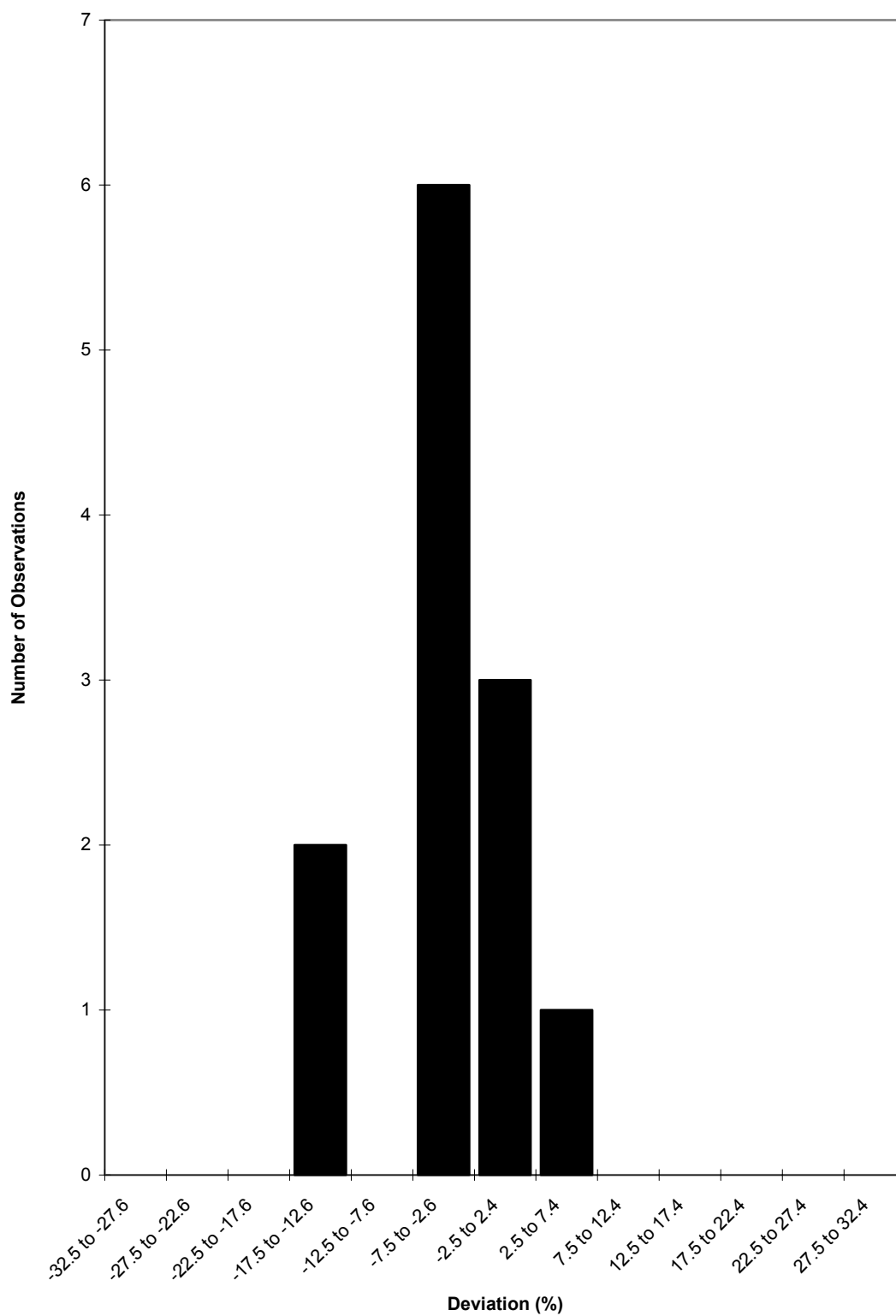
Figure 8 ^{238}Pu low level results

Figure 9 - Reported ^{239}Pu results (low level)

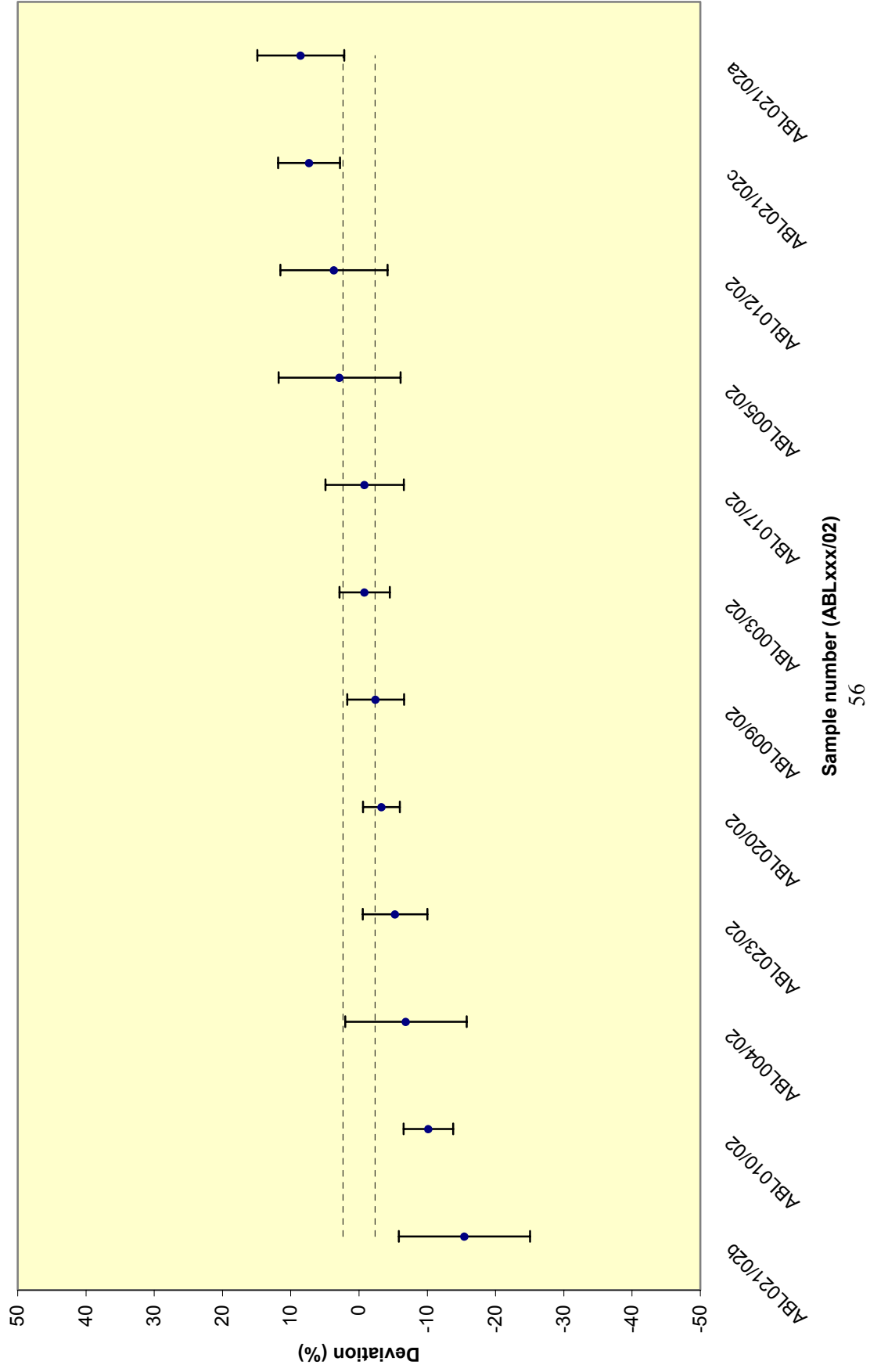


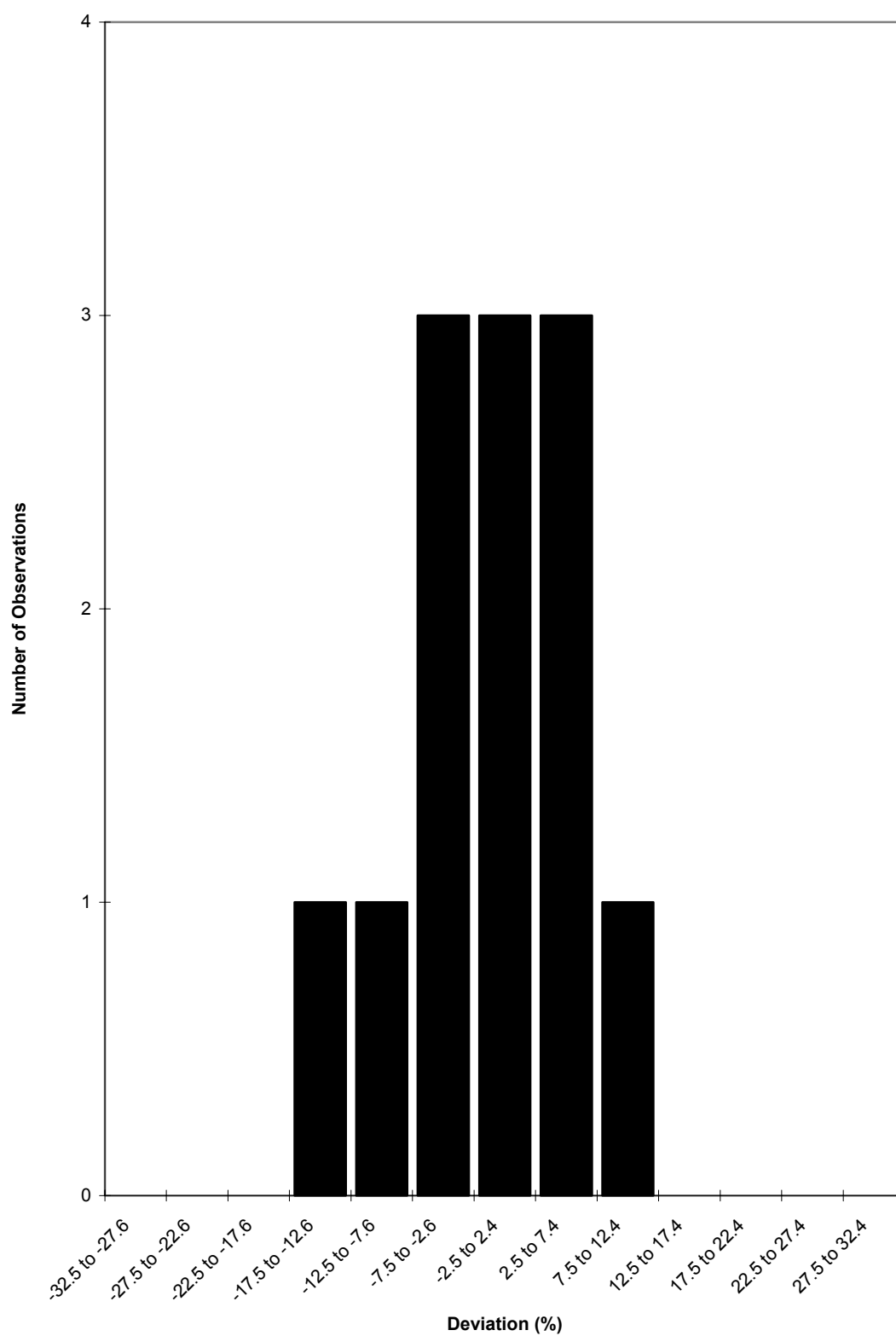
Figure 10 ^{239}Pu low level results

Figure 11 - Reported ²⁴¹Am results (low level)

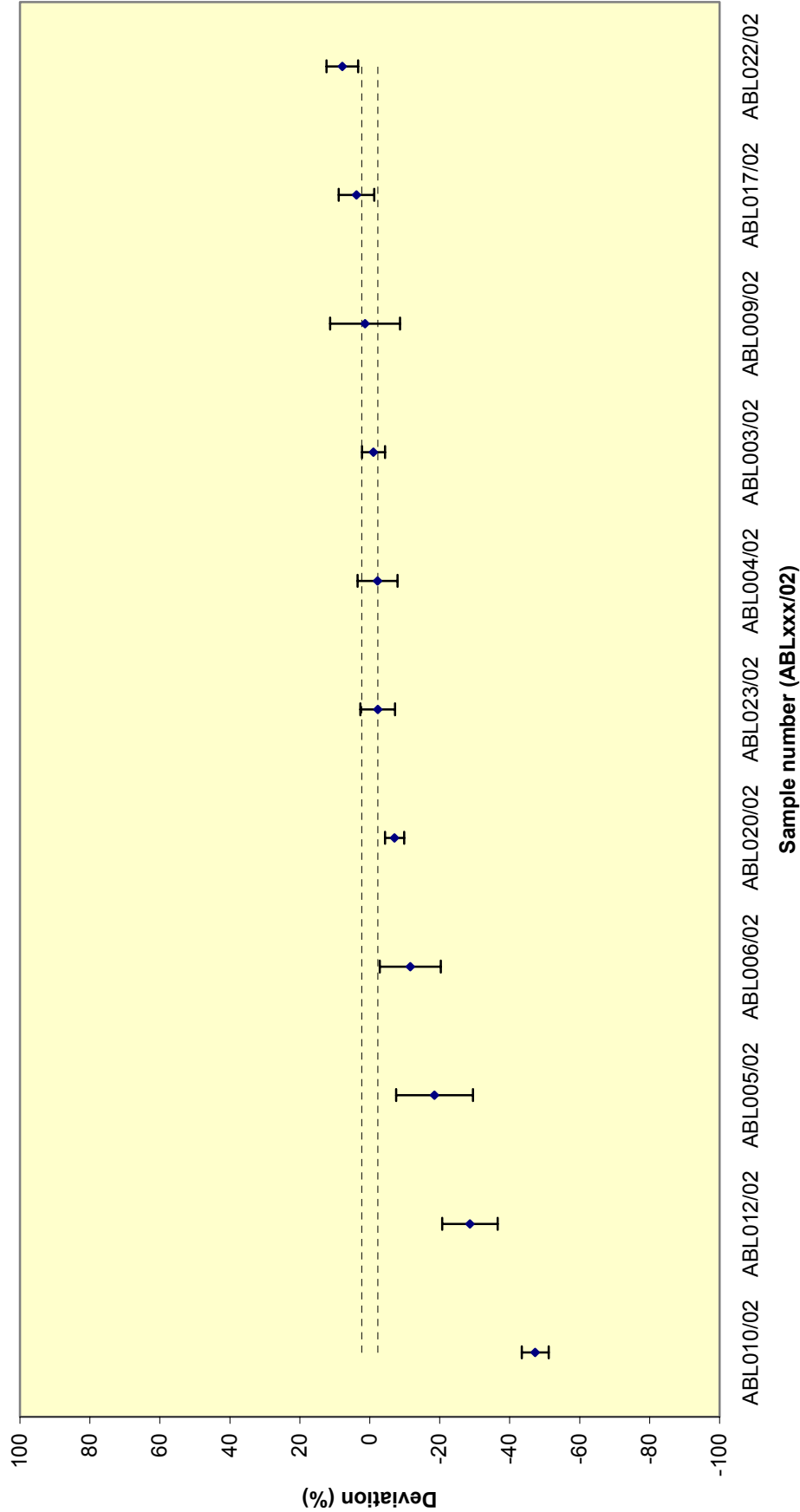


Figure 12 ^{241}Am low level results
(One outside limits of plot)

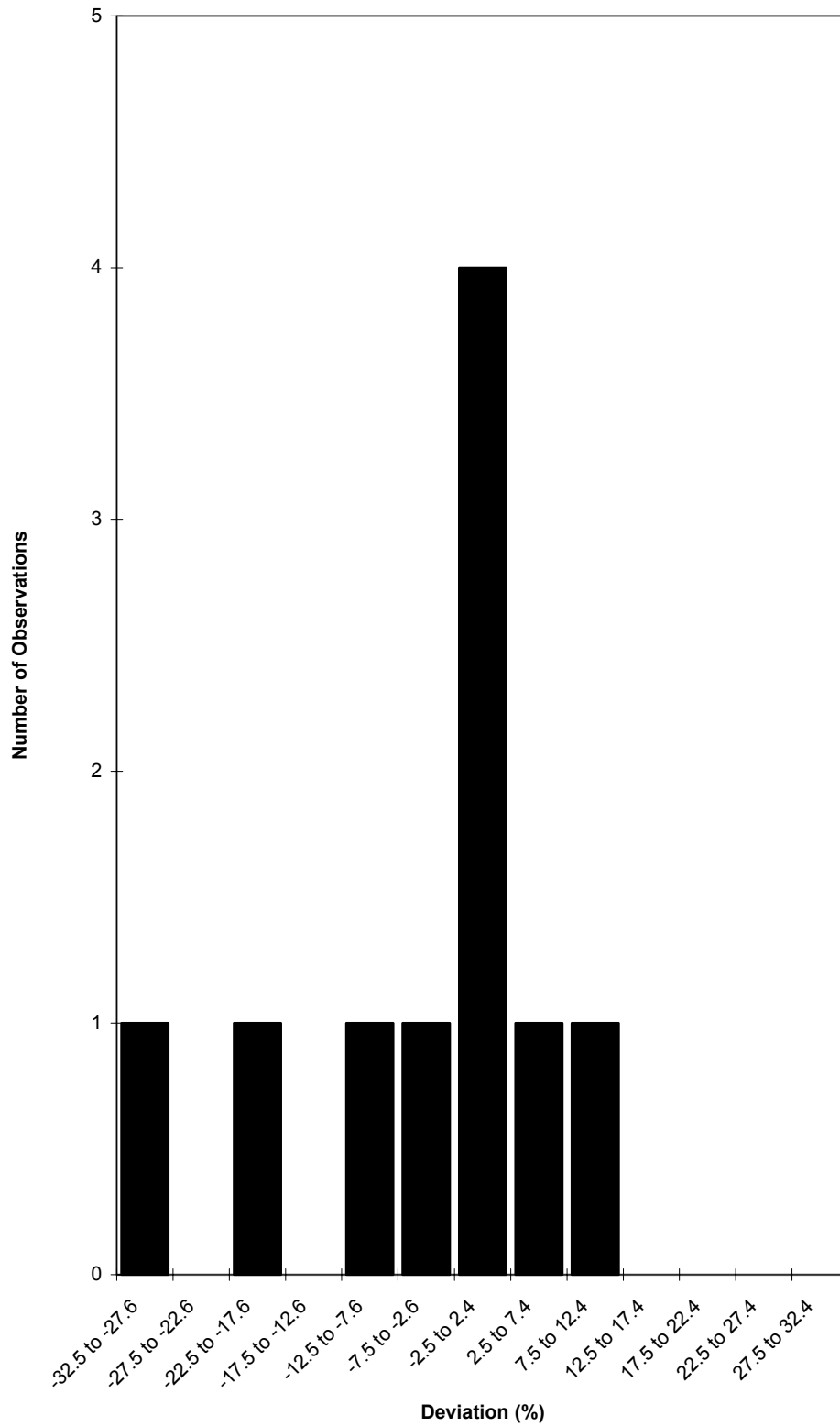


Figure 13 - Reported ^{90}Sr results (high level)

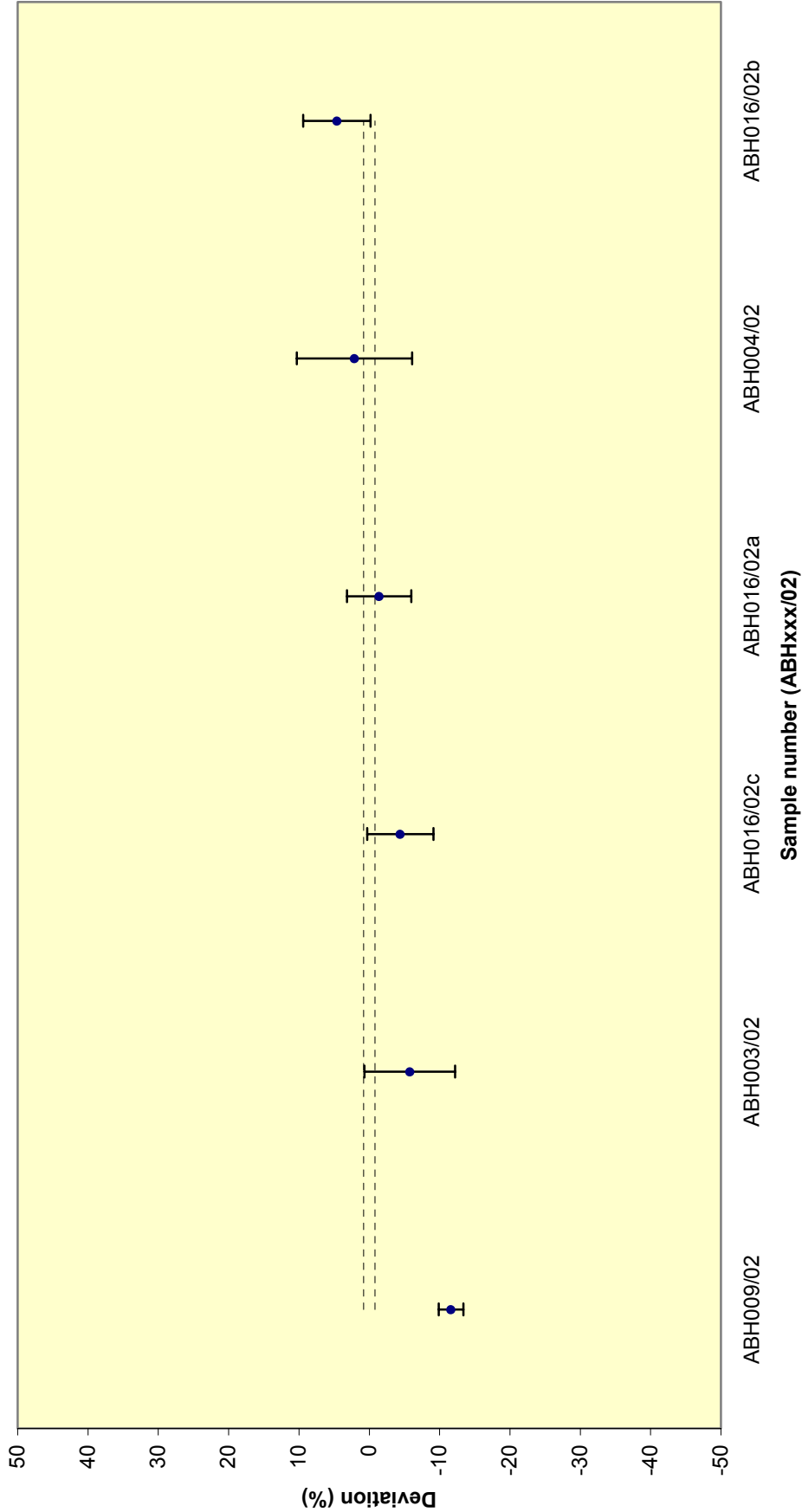


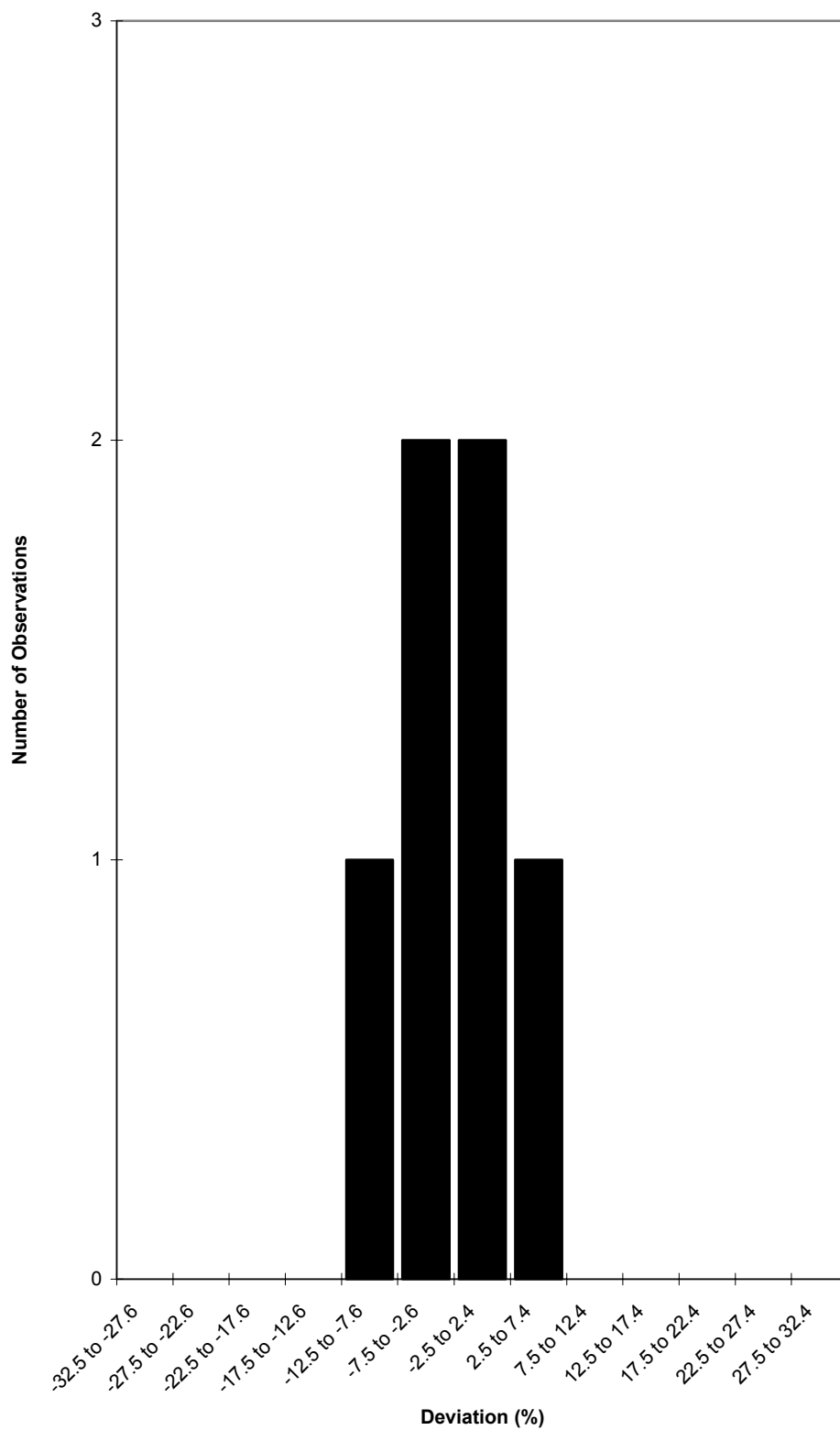
Figure 14 ^{90}Sr high level results

Figure 15 - Reported ²²⁶Ra results (high level)

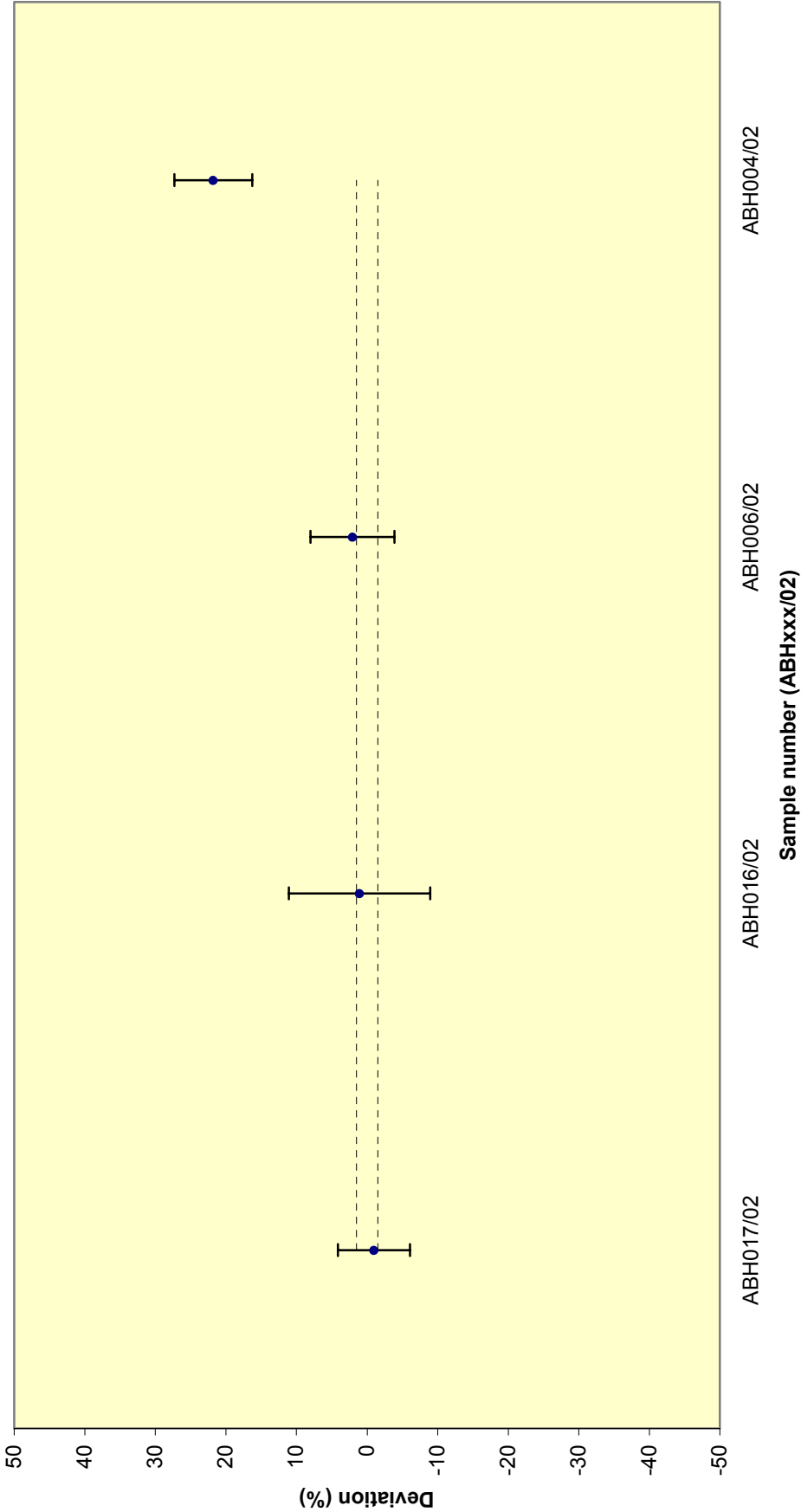


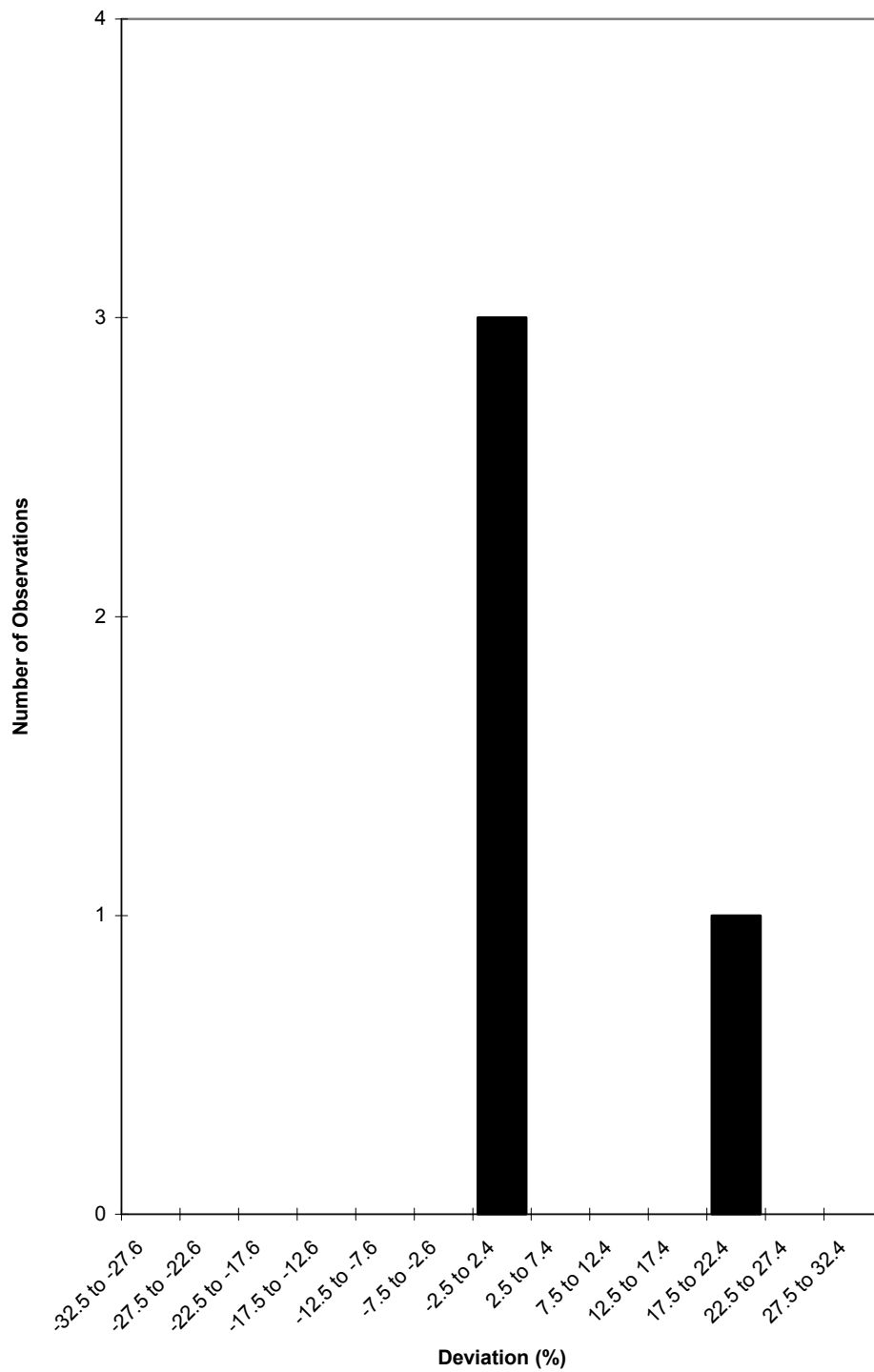
Figure 16 ^{226}Ra high level results

Figure 17 - Reported ^{238}Pu results (high level)

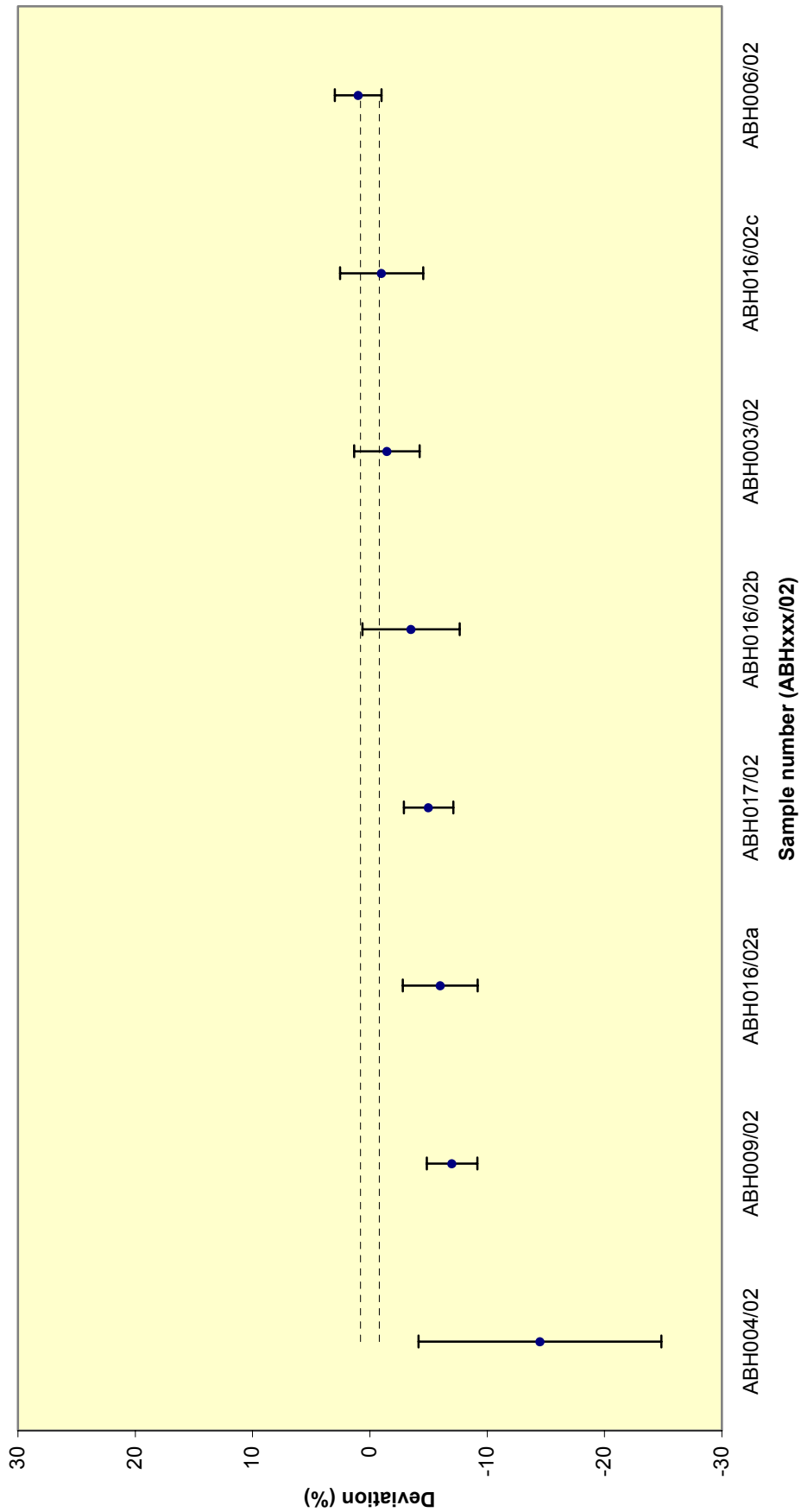


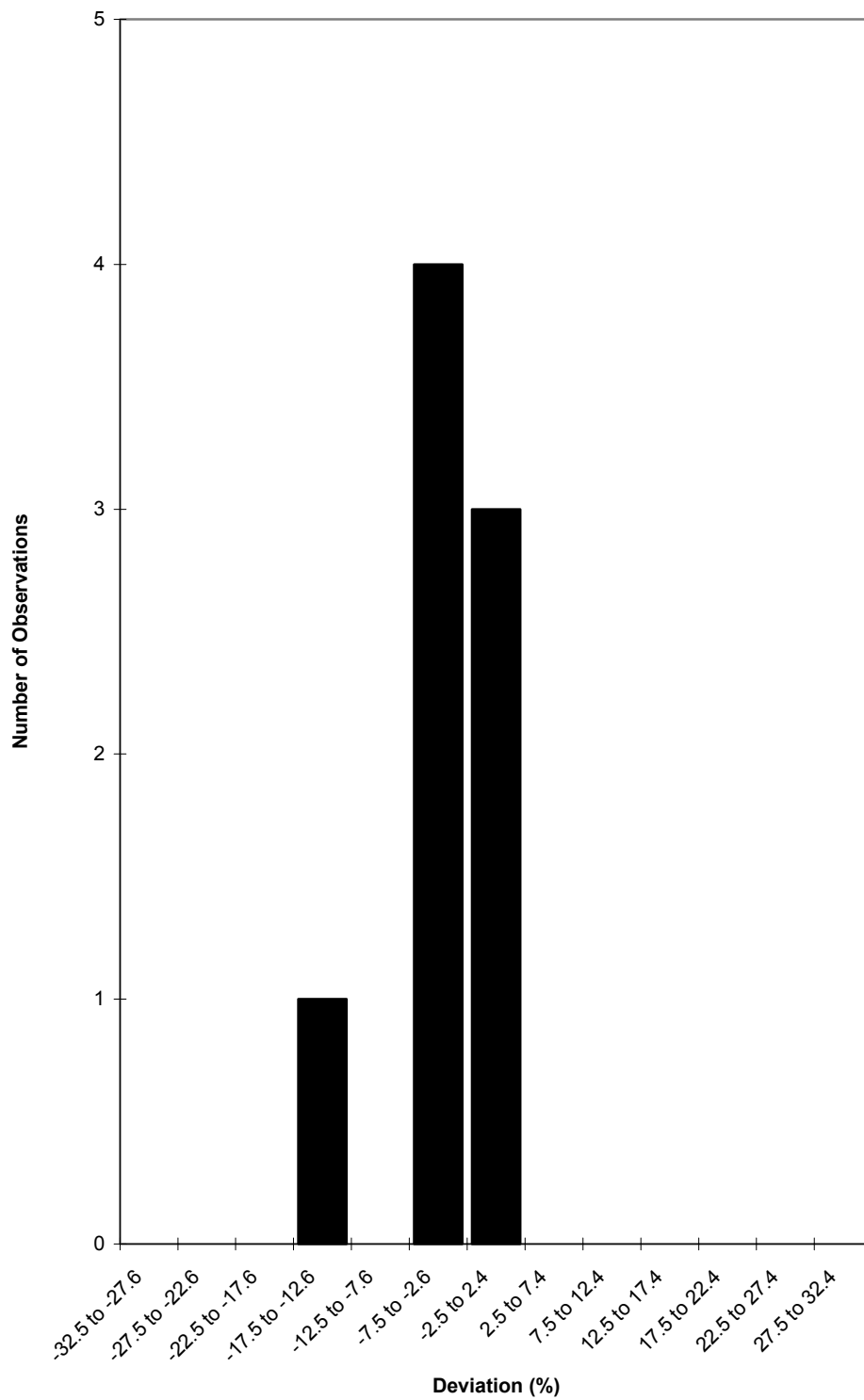
Figure 18 ^{238}Pu high level results

Figure 19 - Reported ^{239}Pu results (high level)

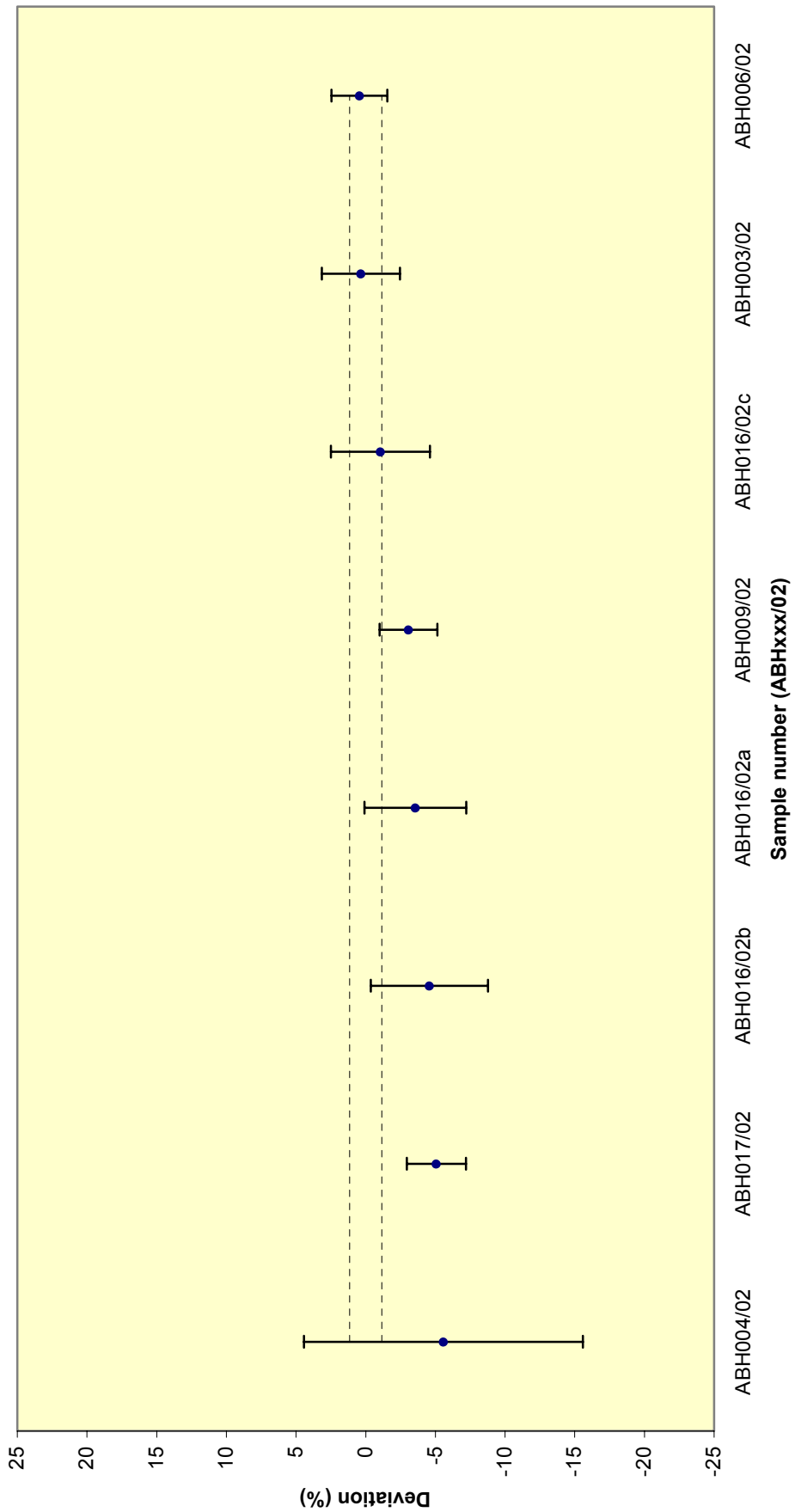


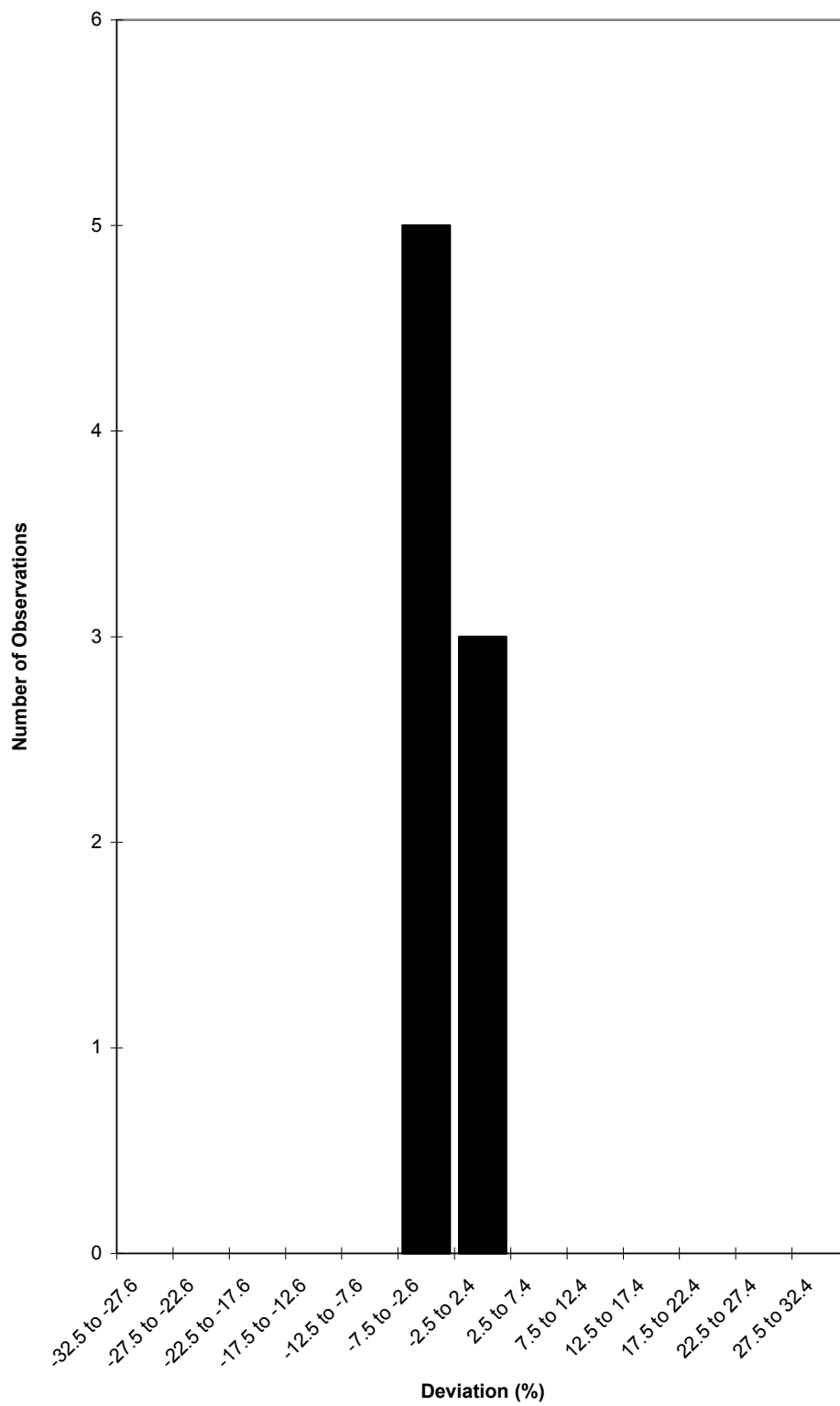
Figure 20 ^{239}Pu high level results

Figure 21 - Reported ^{241}Am results (high level)

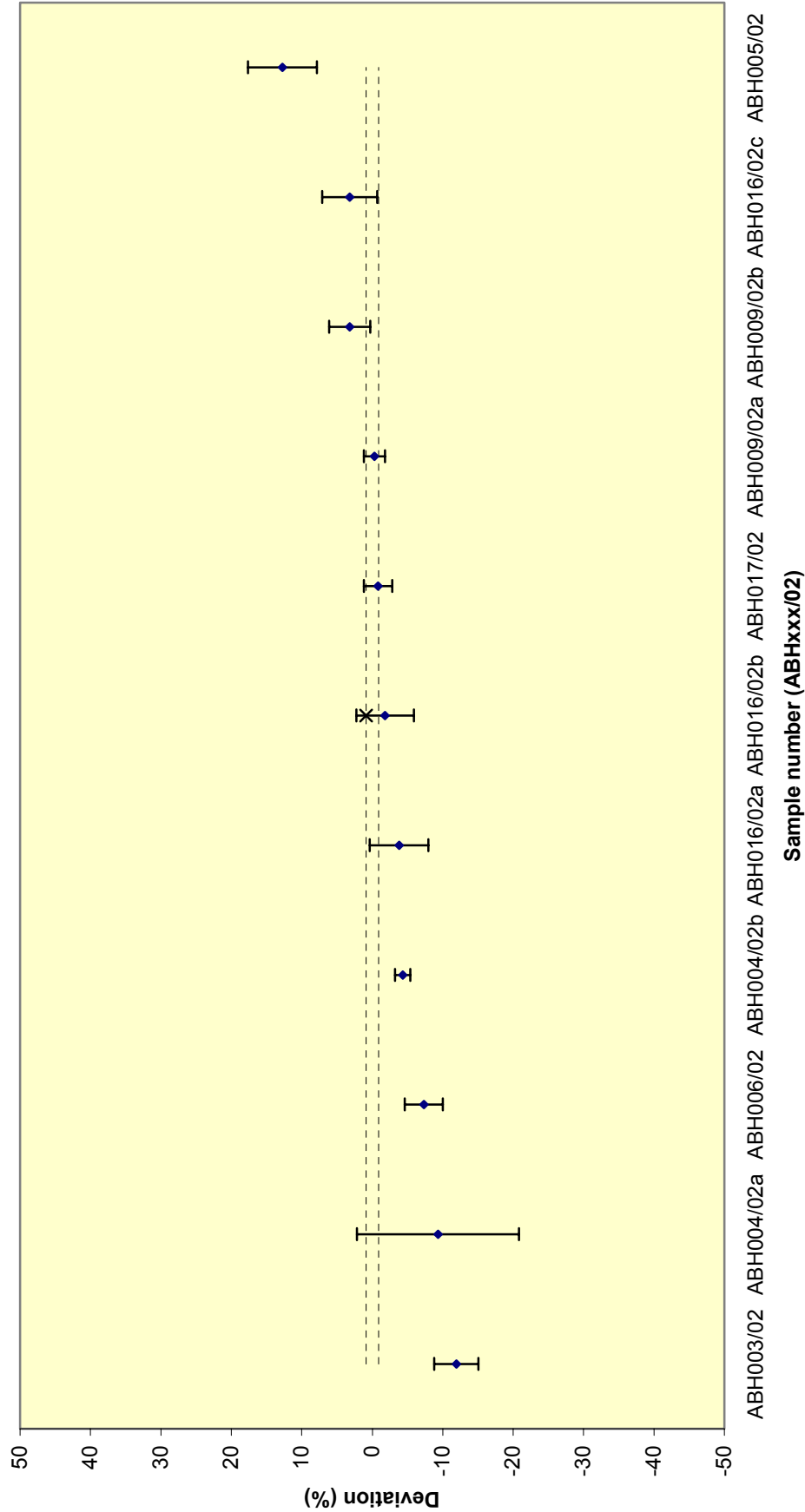


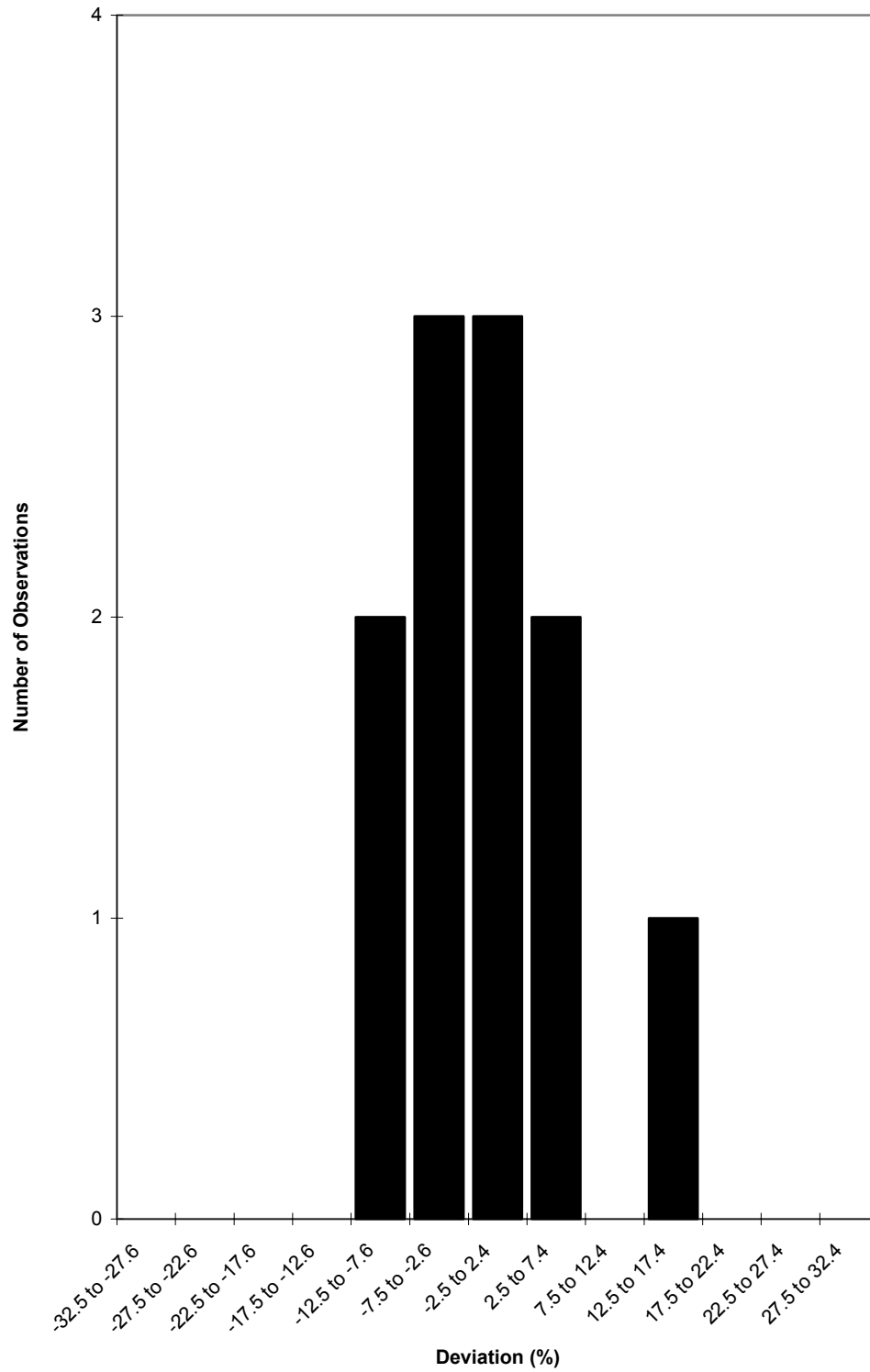
Figure 22 ^{241}Am high level results

Figure 23 - Reported ^3H results (Low level)

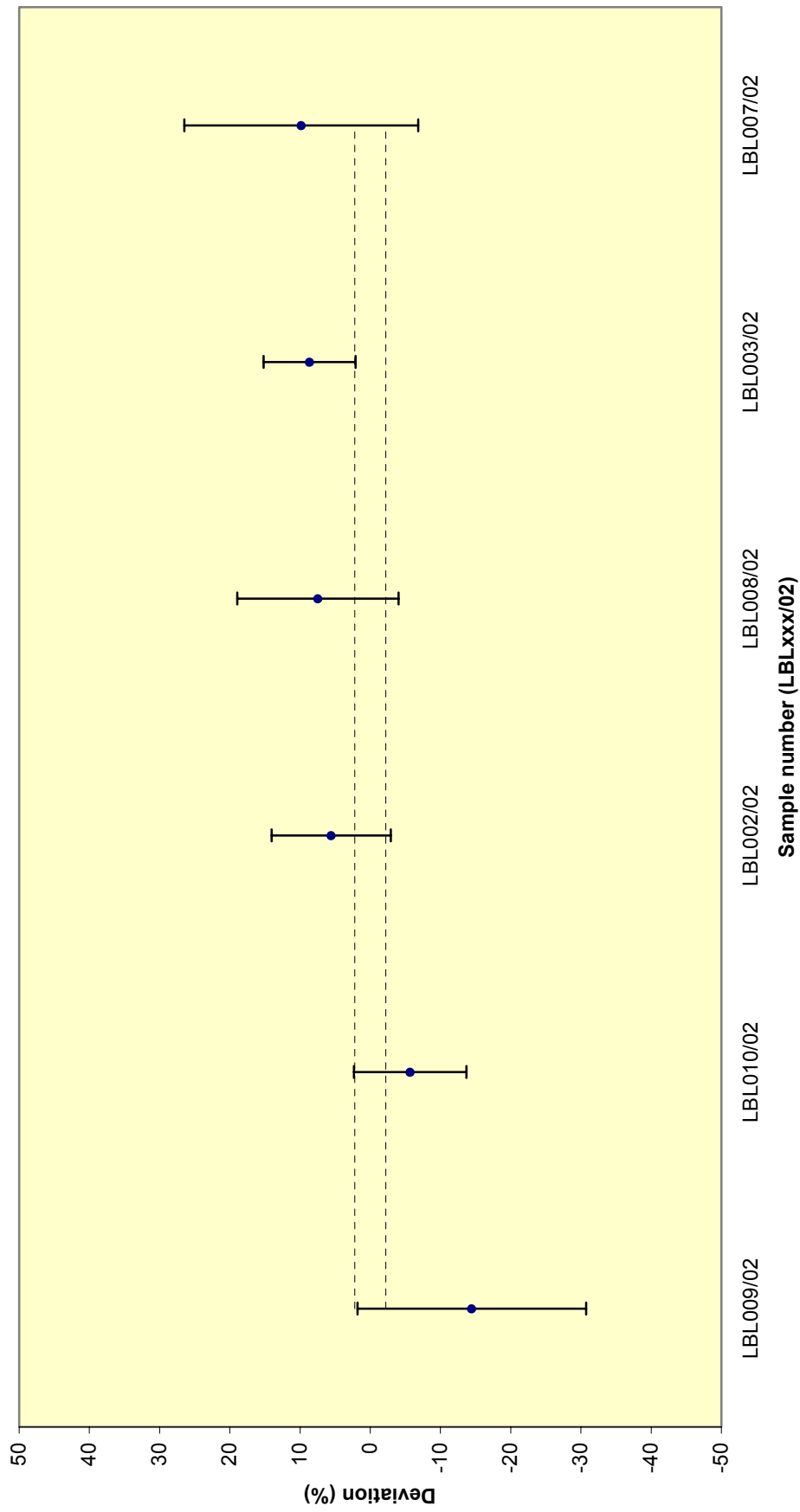


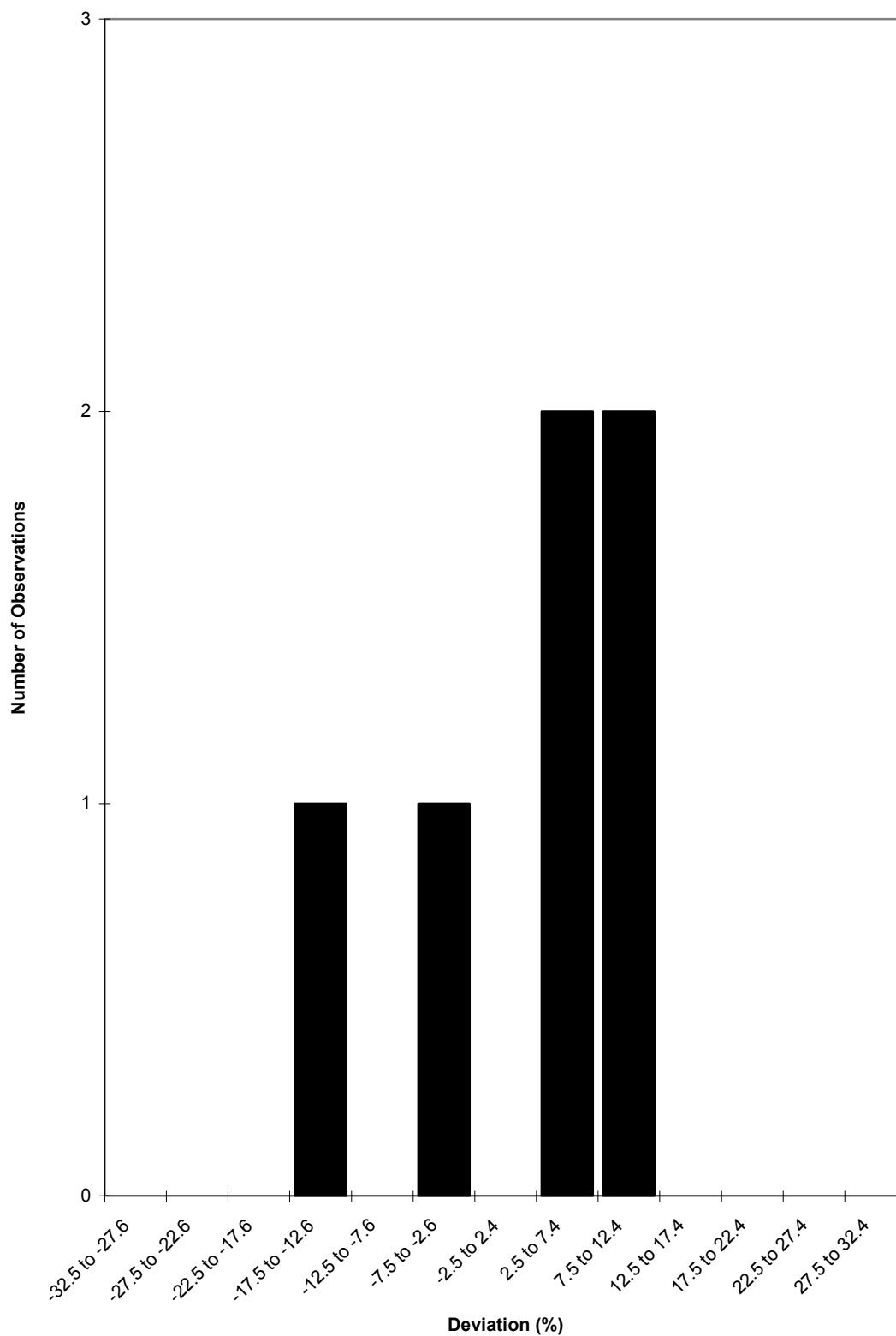
Figure 24 ^3H Low level results

Figure 25 - Reported ^{14}C results (Low level)

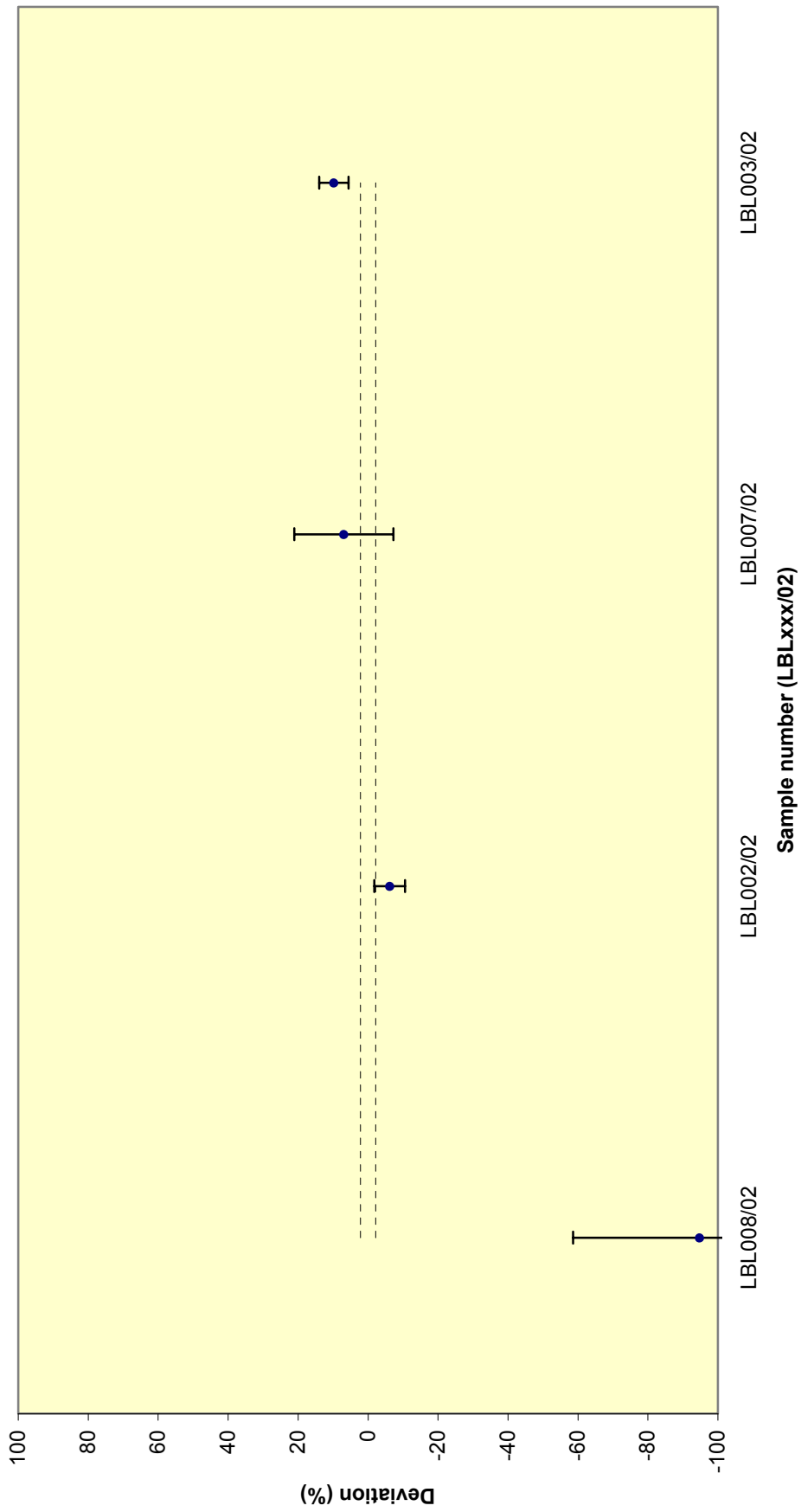


Figure 26 ^{14}C Low level results
(One outside limits of plot)

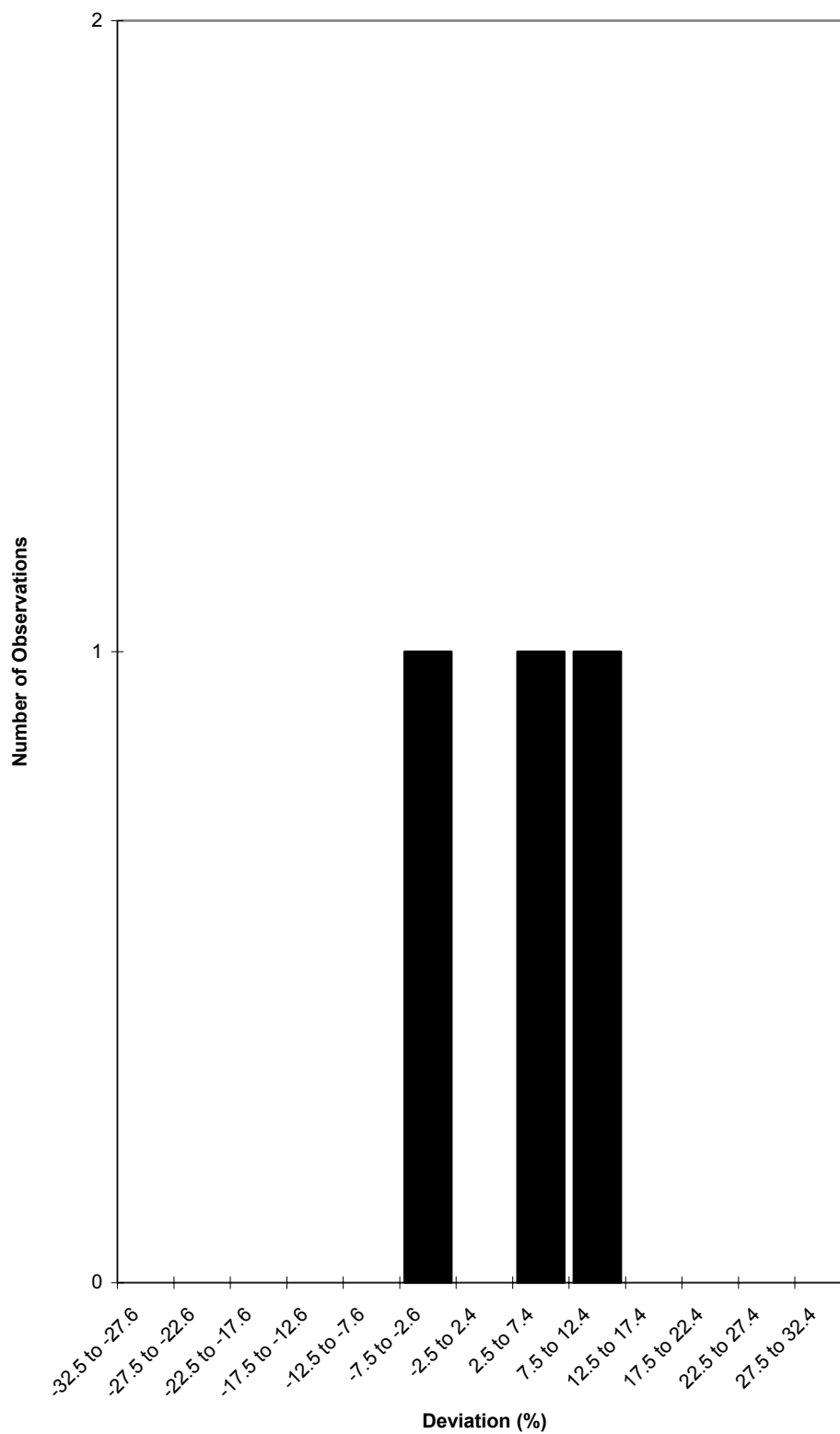


Figure 27 - Reported ³⁵S results (Low level)

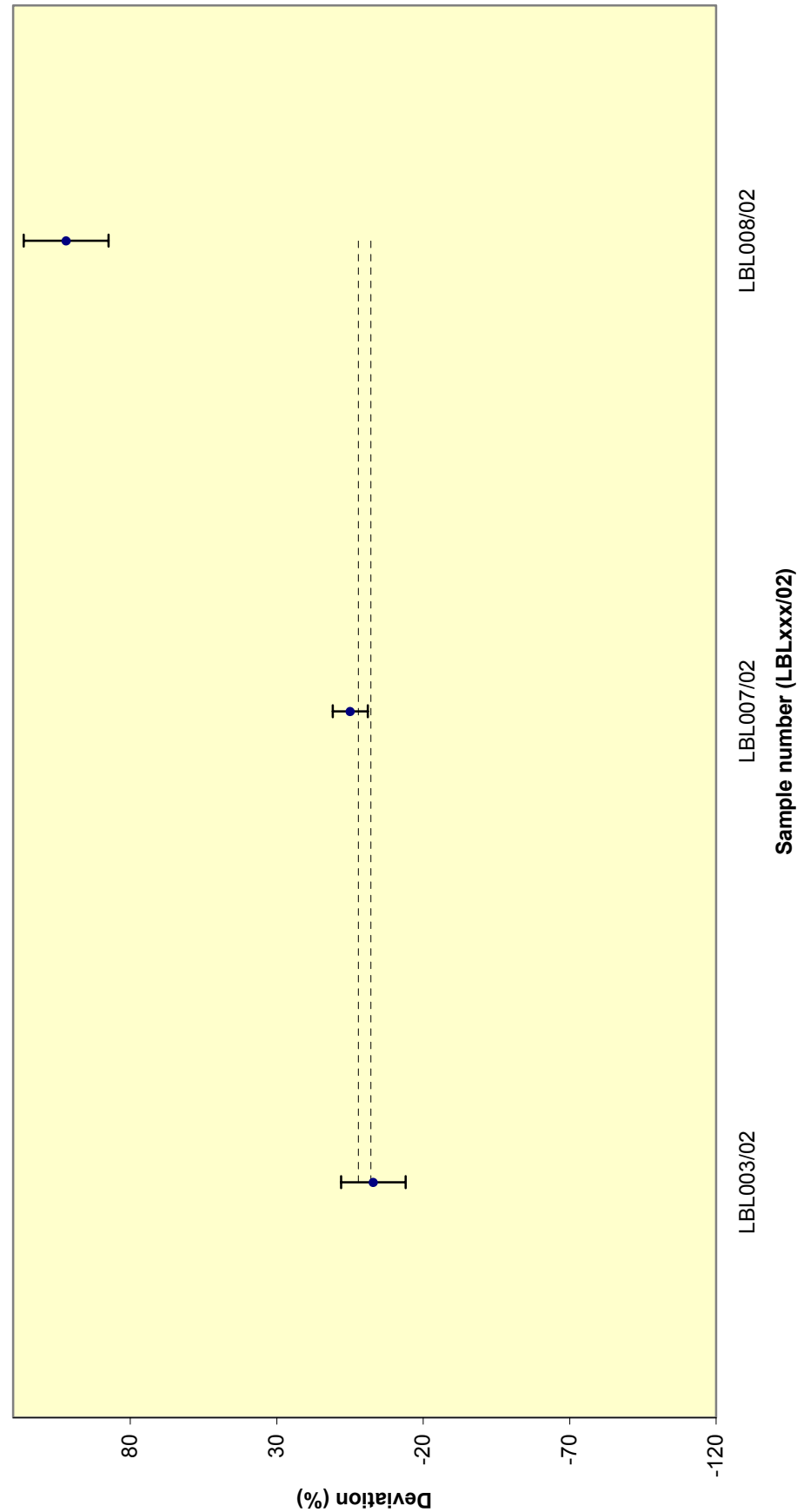


Figure 28 ^{35}S Low level results
(One outside limits of plot)

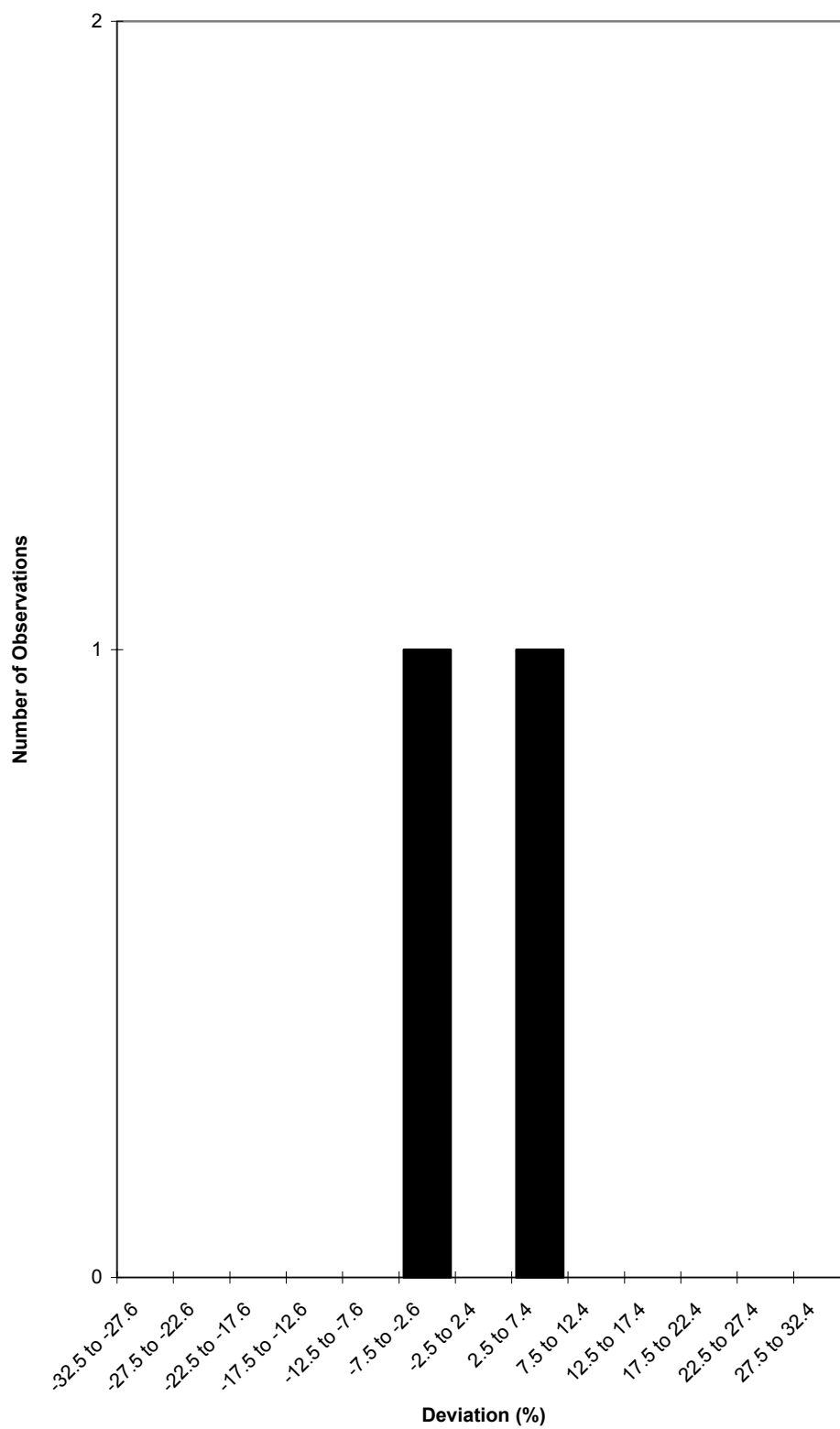


Figure 29 - Reported ^3H results (High level)

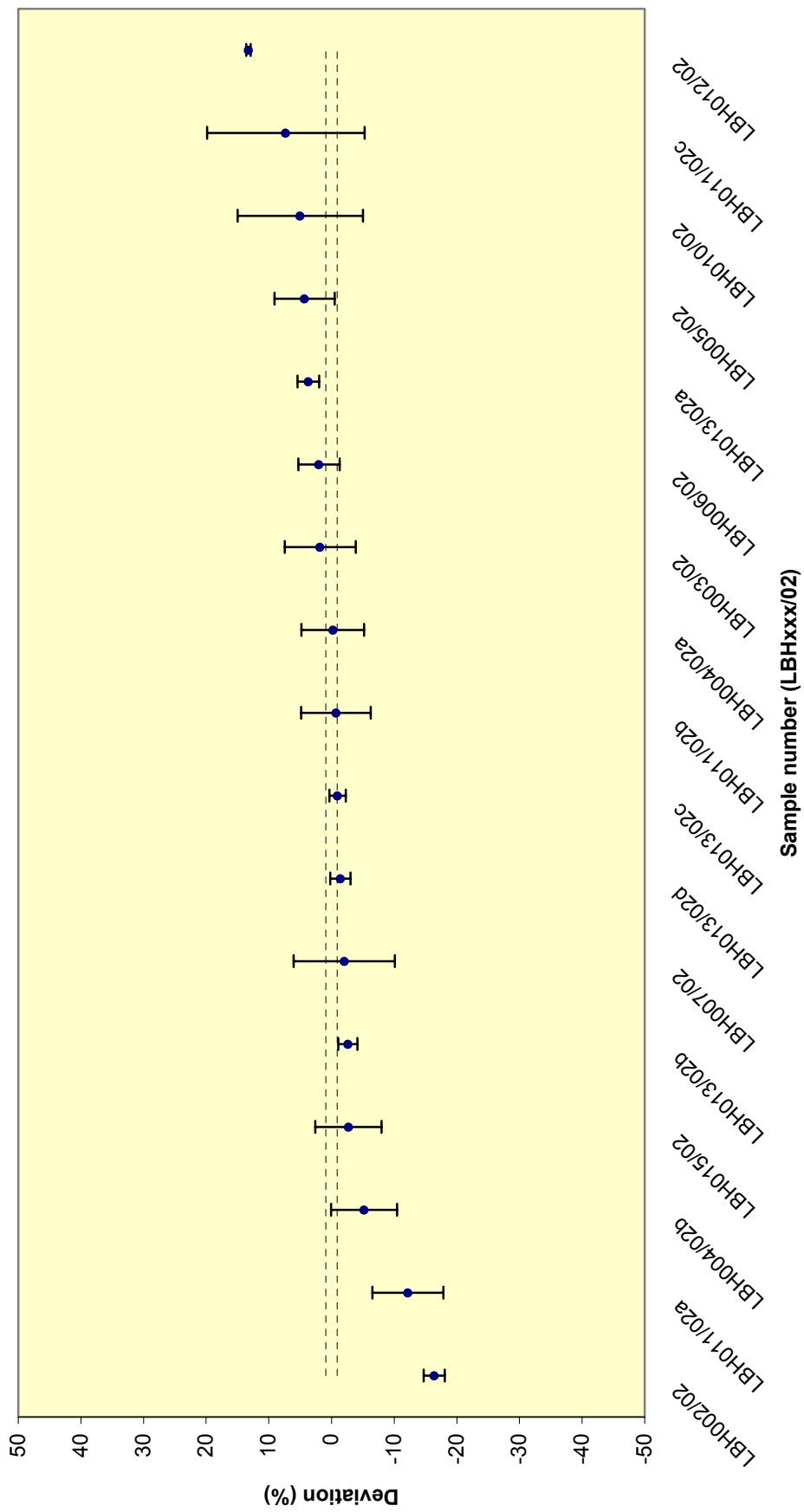


Figure 30 ^3H High level results
(One outside limits of plot)

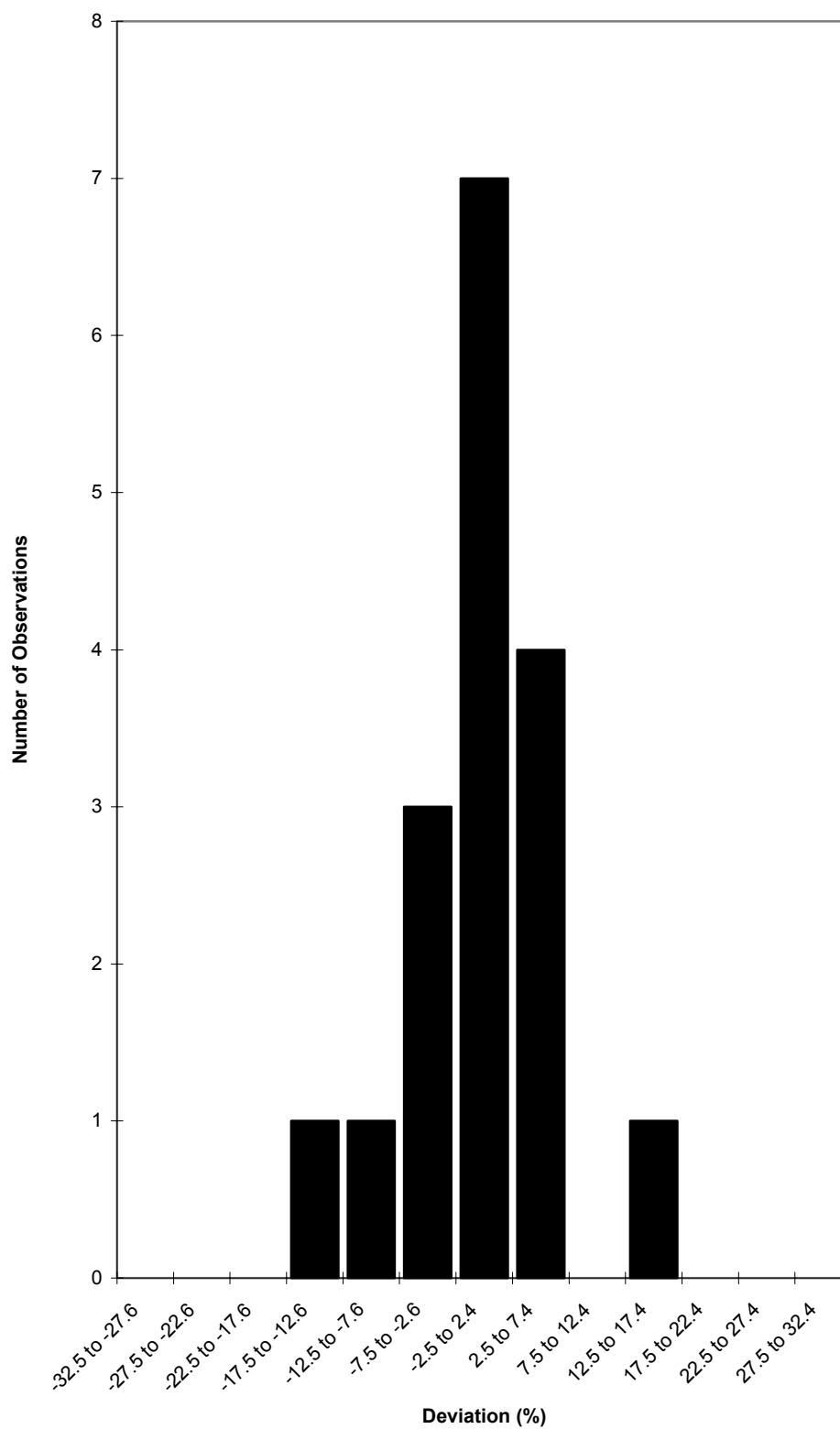


Figure 31 - Reported ¹⁴C results (High level)

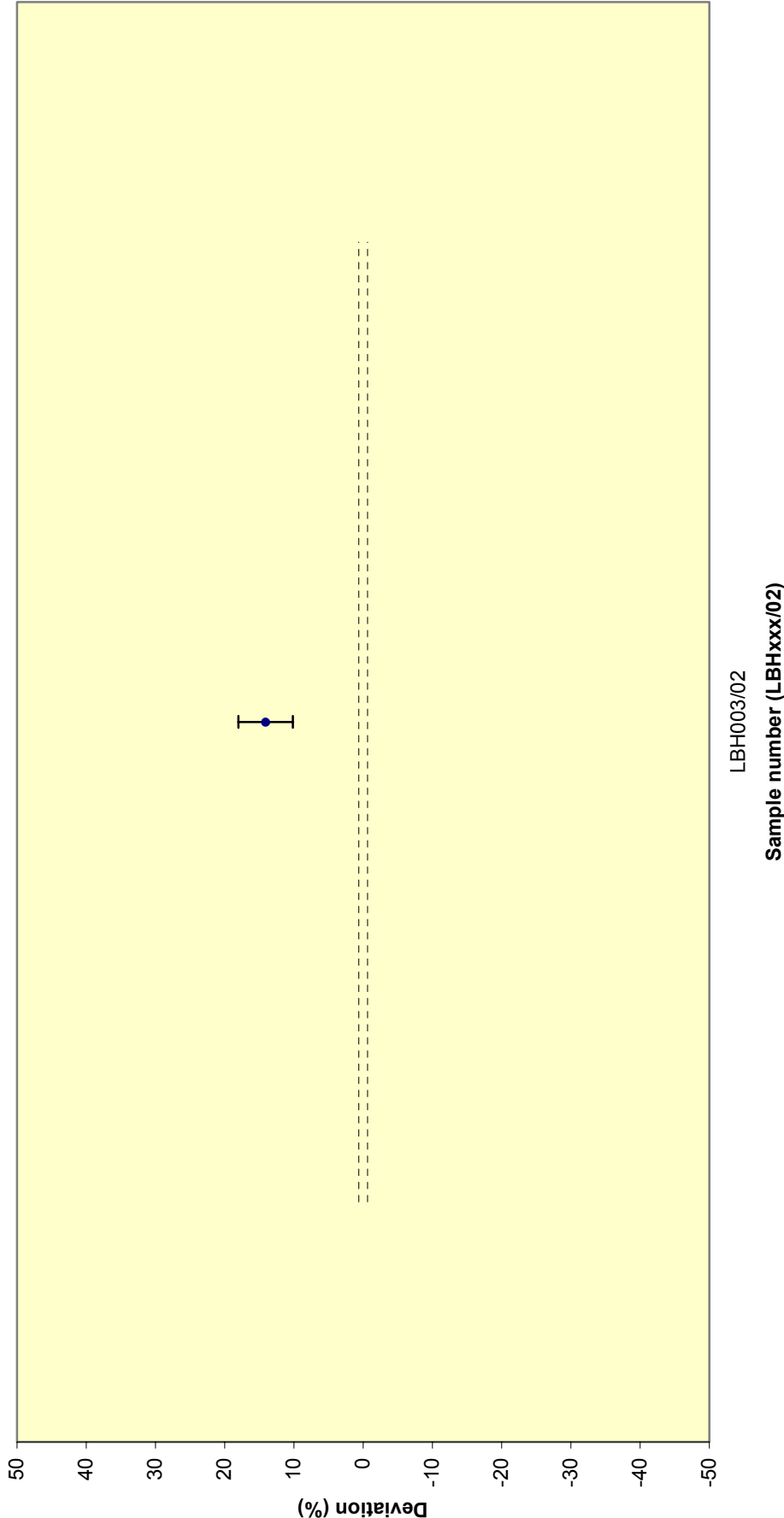


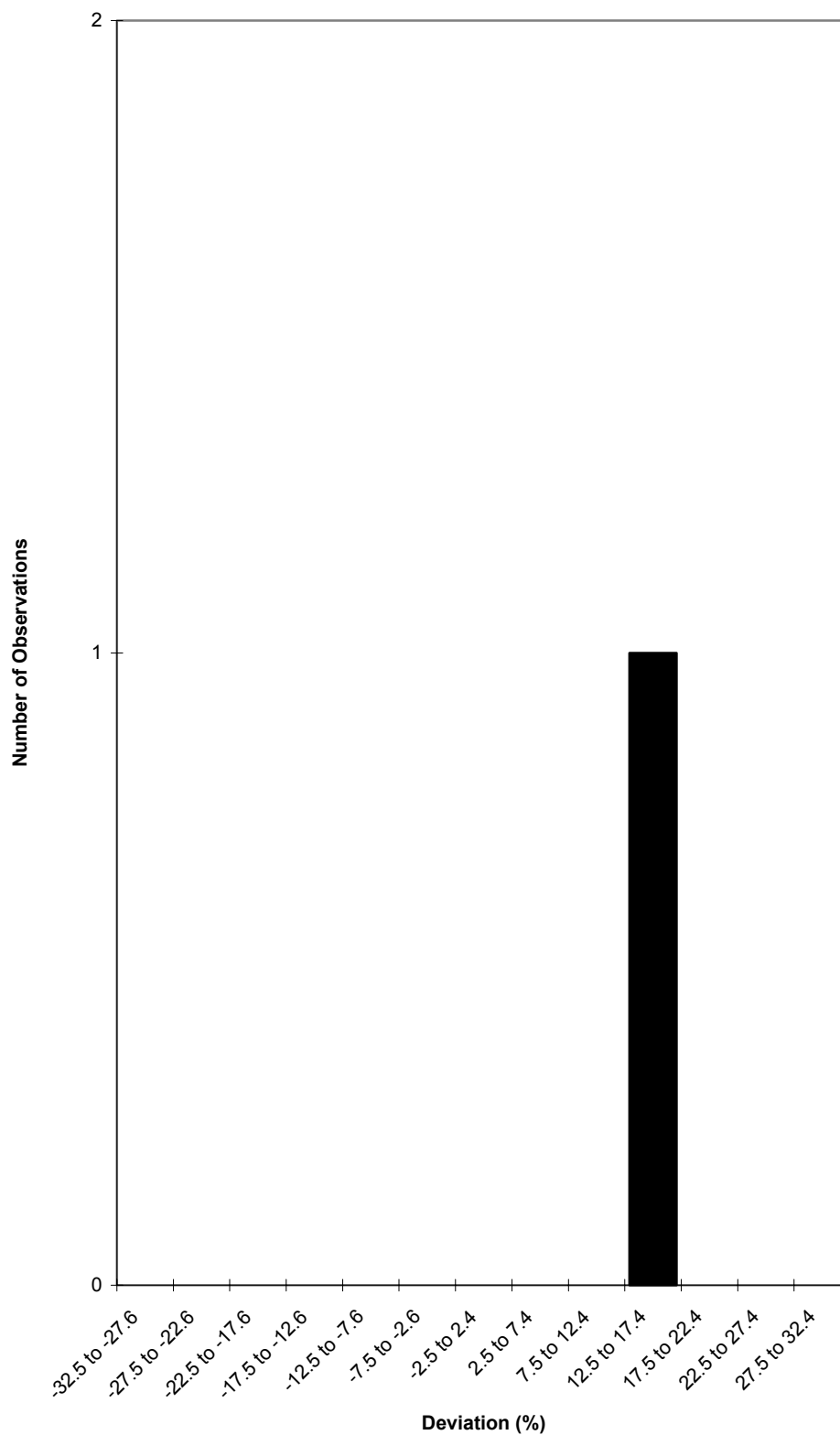
Figure 32 ^{14}C High level results

Figure 33 - Reported ³⁵S results (High level)

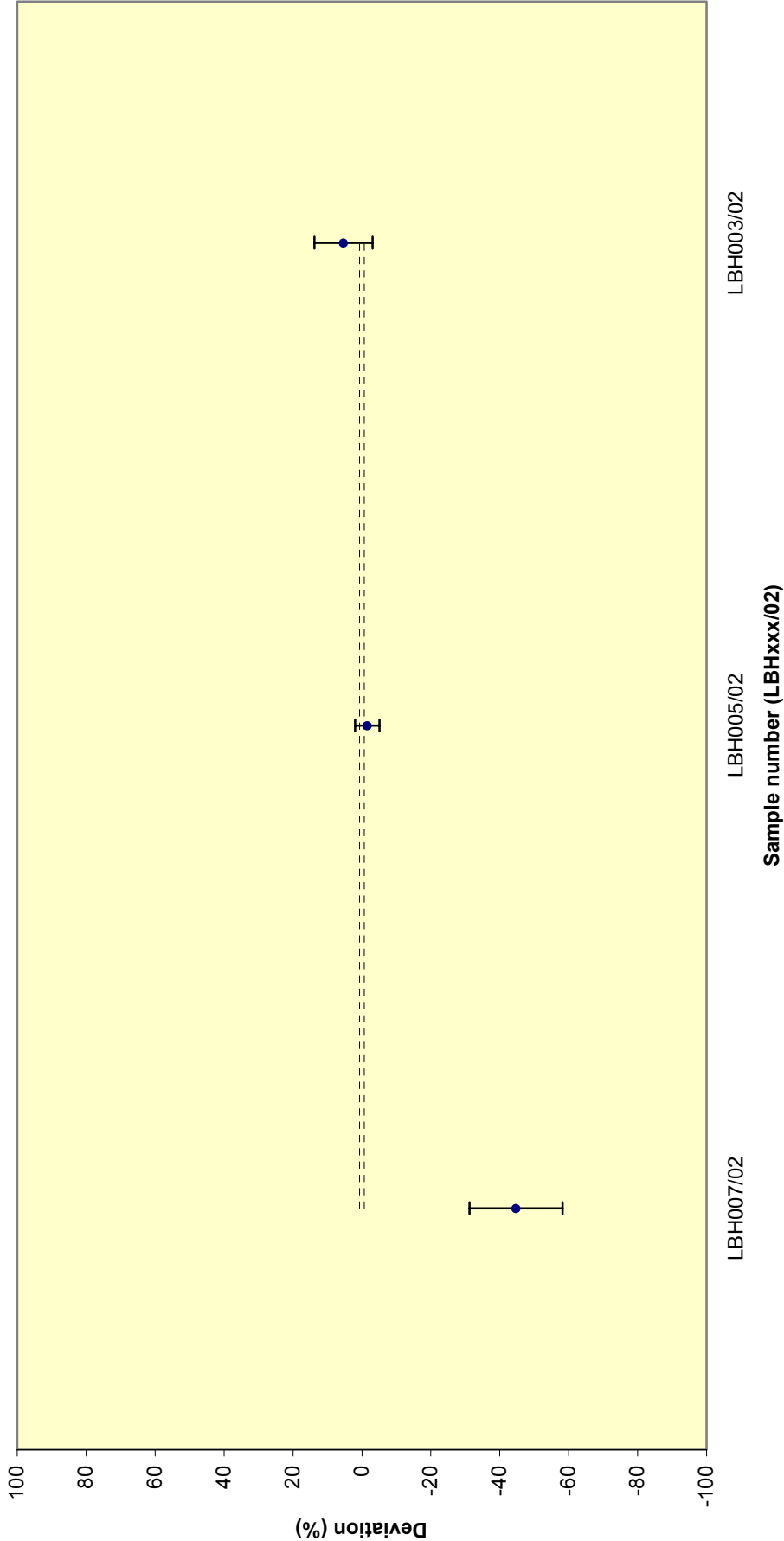


Figure 34 ^{35}S High level results
(One outside limits of plot)

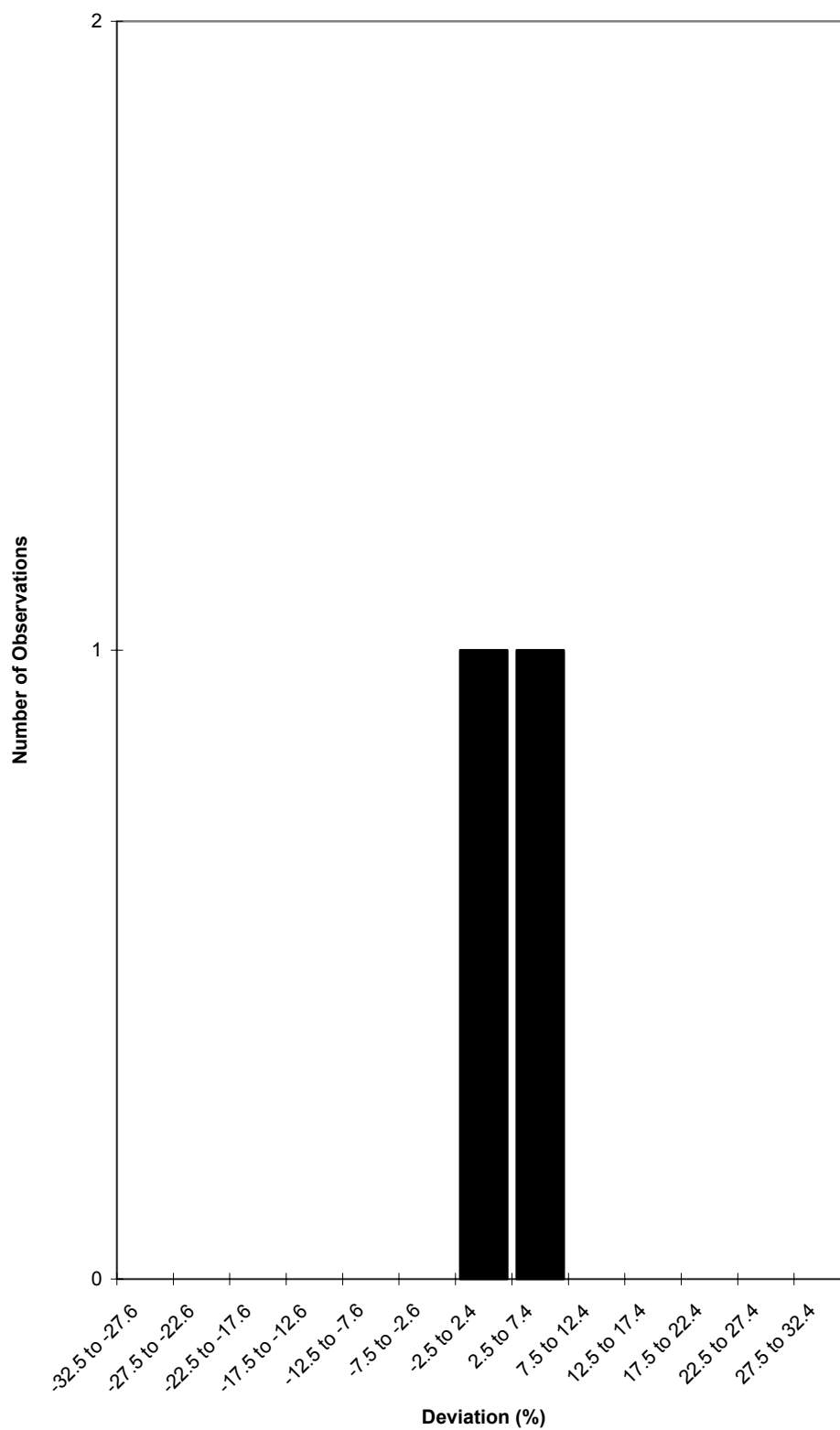


Figure 35 - Reported ^{22}Na results (low level)

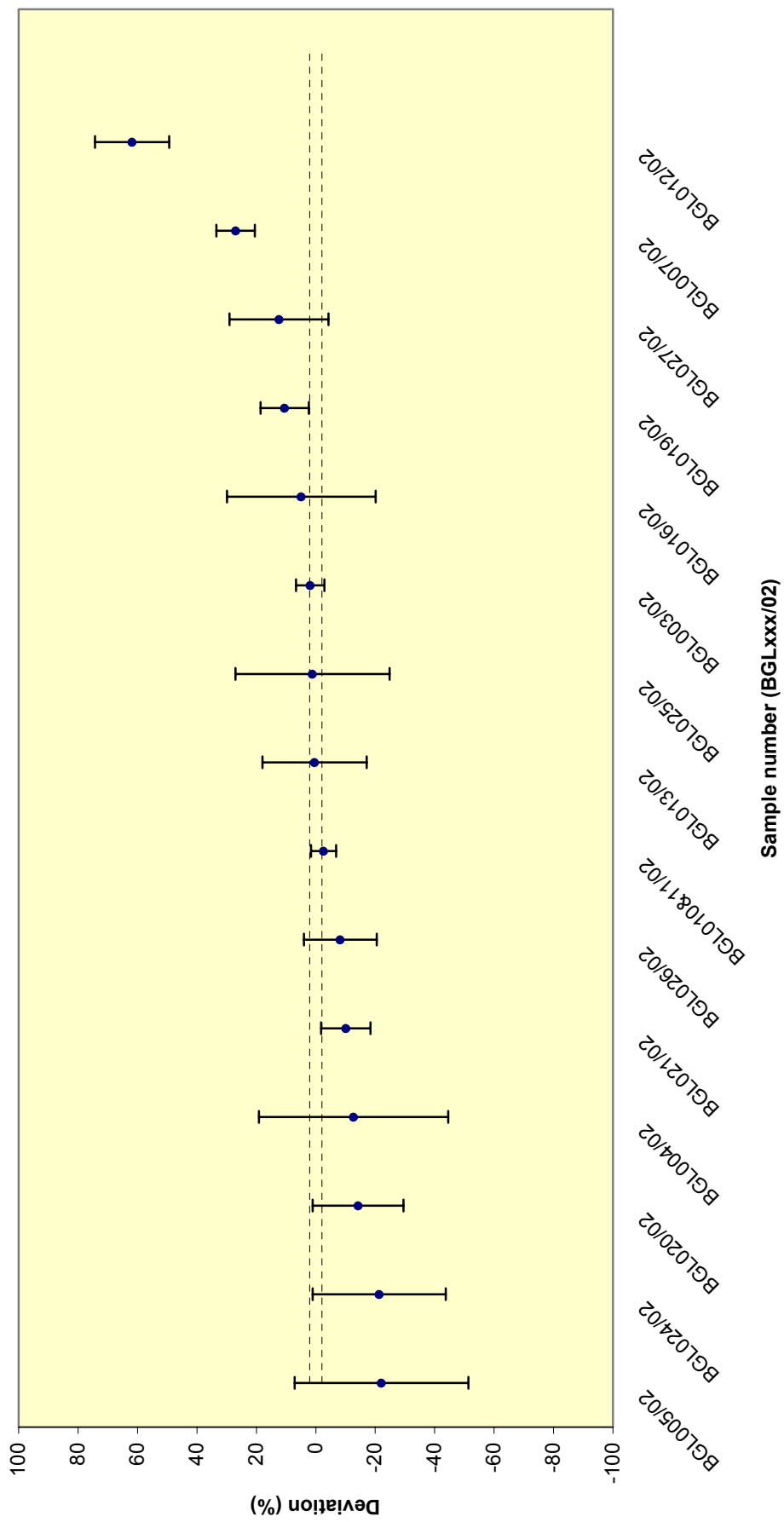


Figure 36 ^{22}Na low level results
(One outside limits of plot)

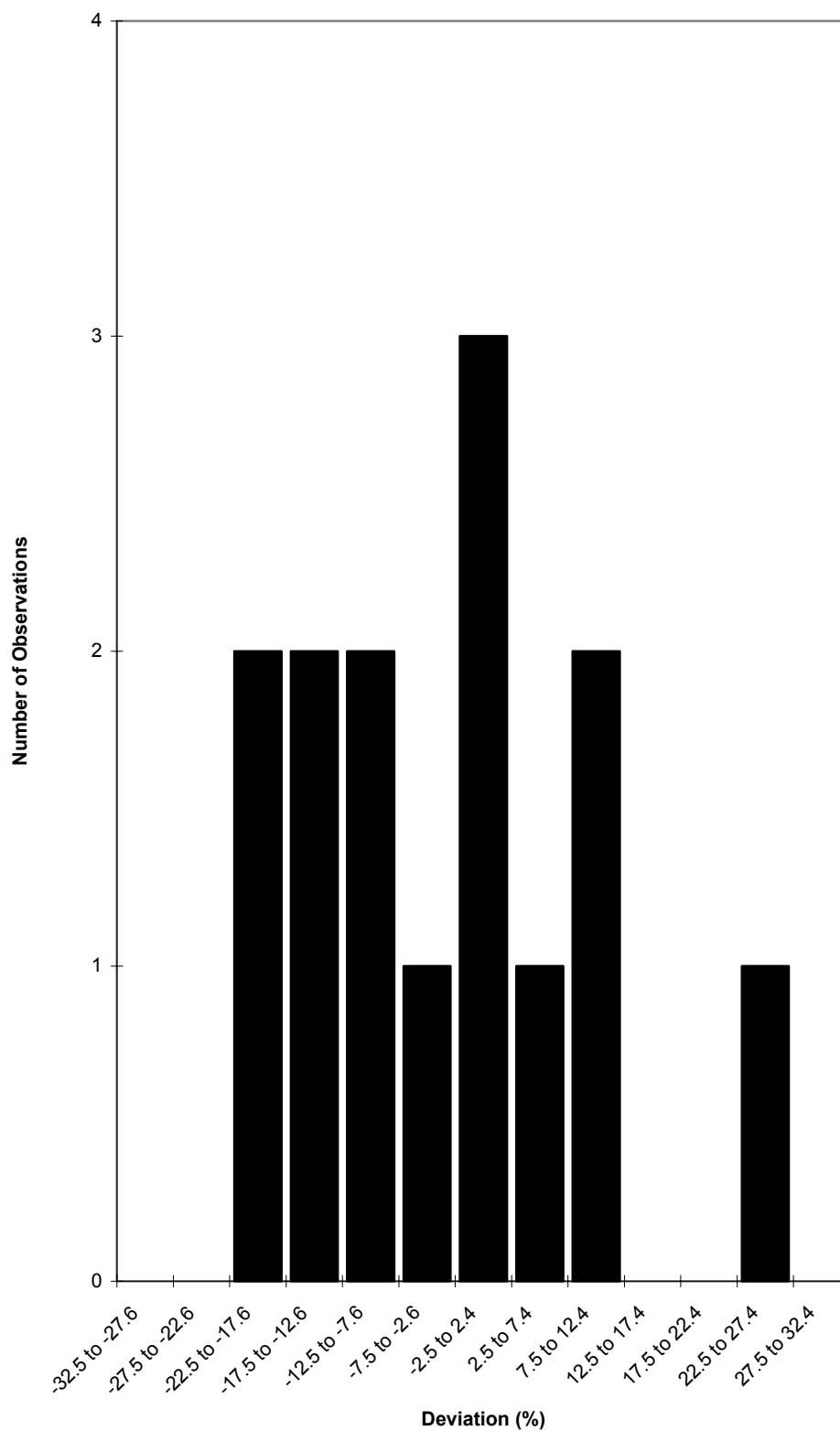


Figure 37 - Reported ^{57}Co results (low level)

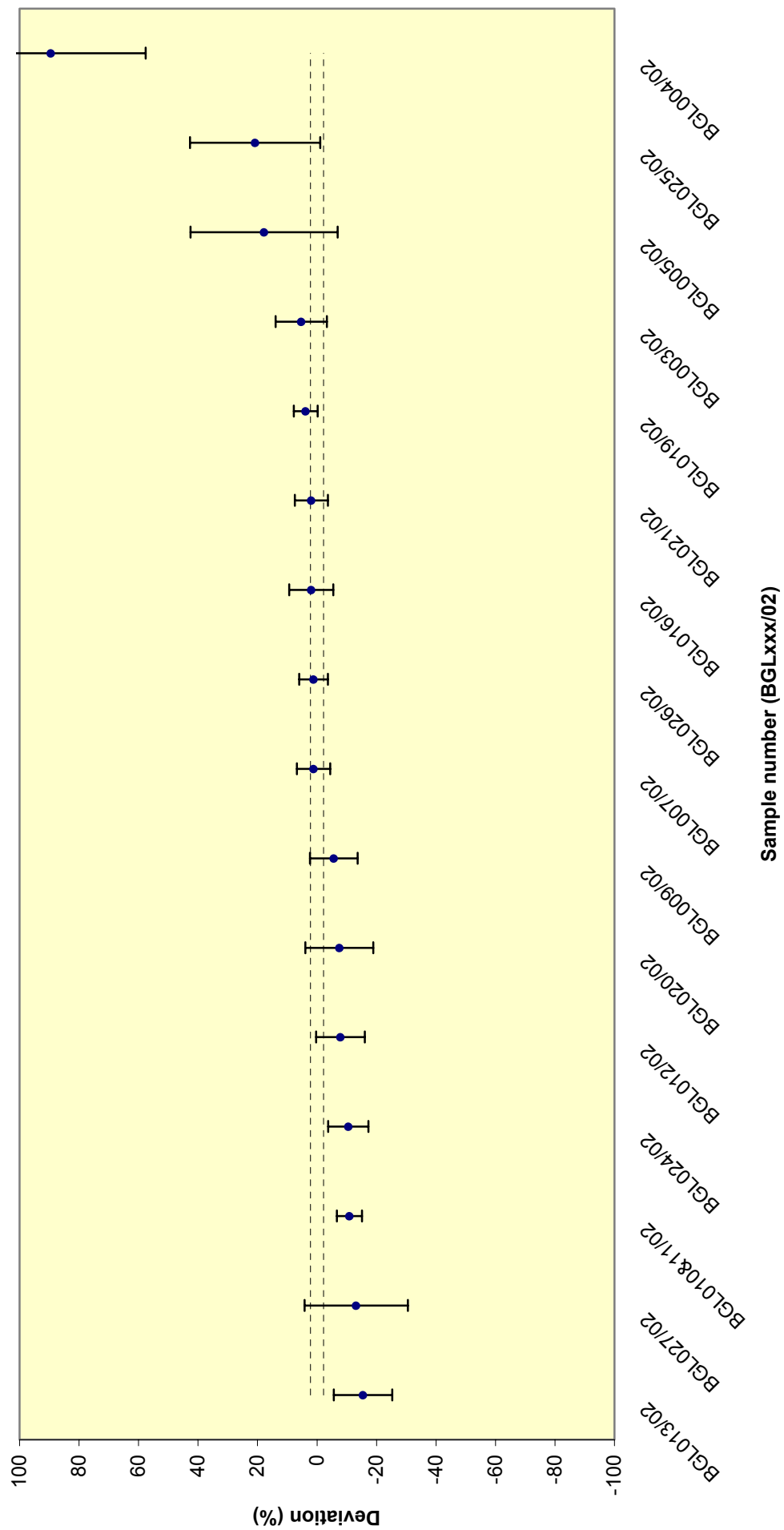


Figure 38 ^{57}Co low level results
(One outside limits of plot)

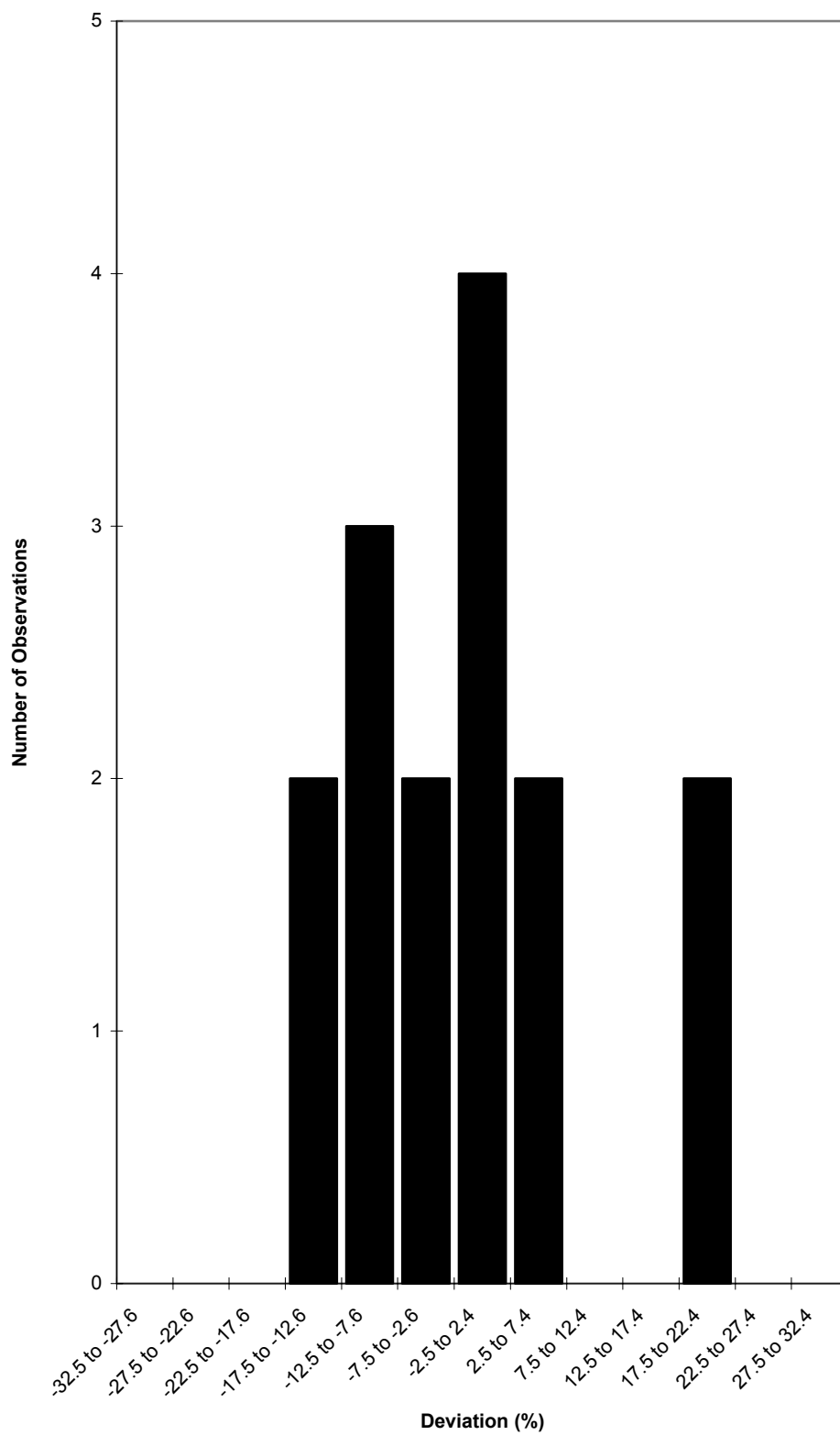


Figure 39 - Reported ^{60}Co results (low level)

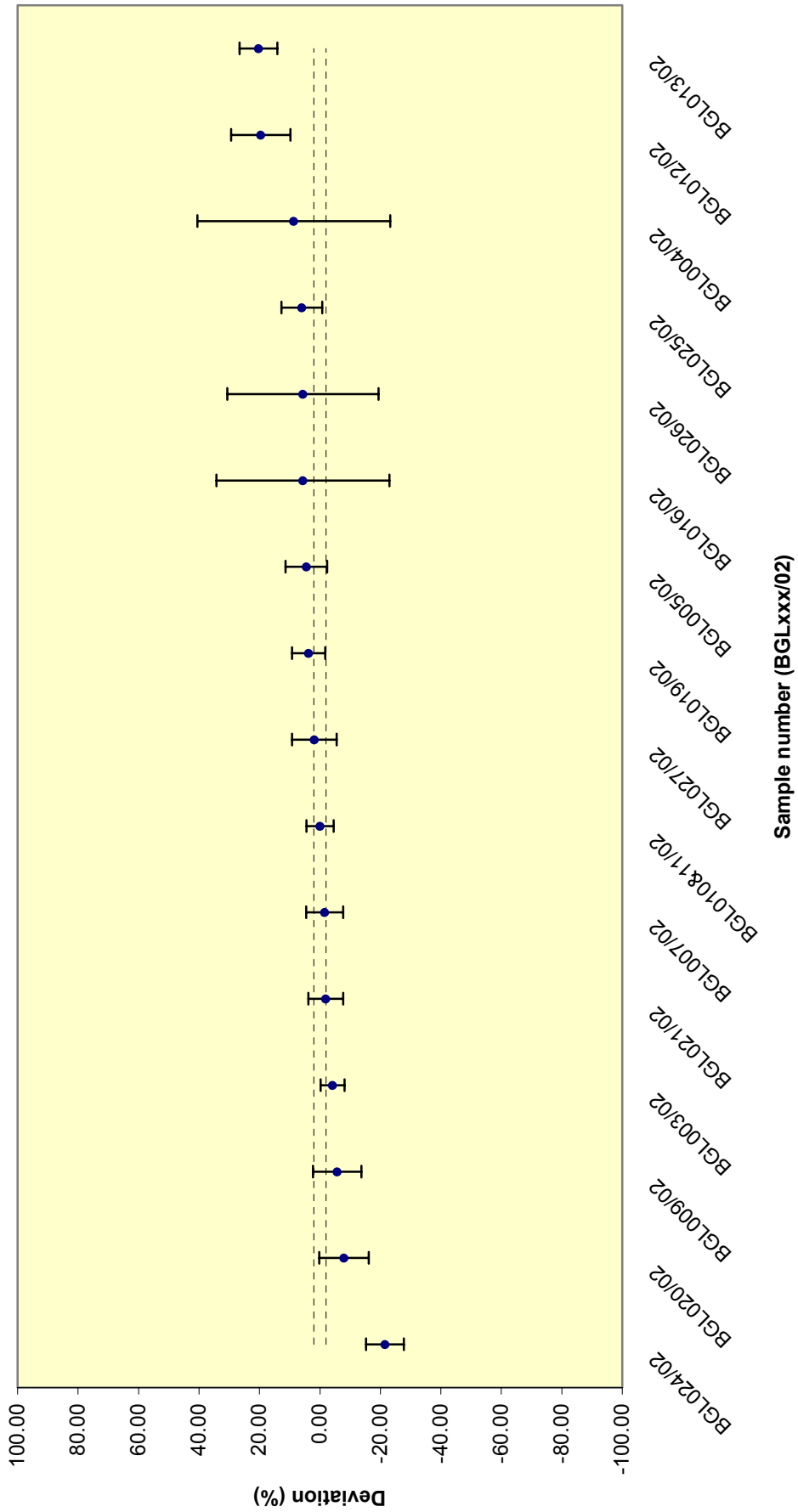


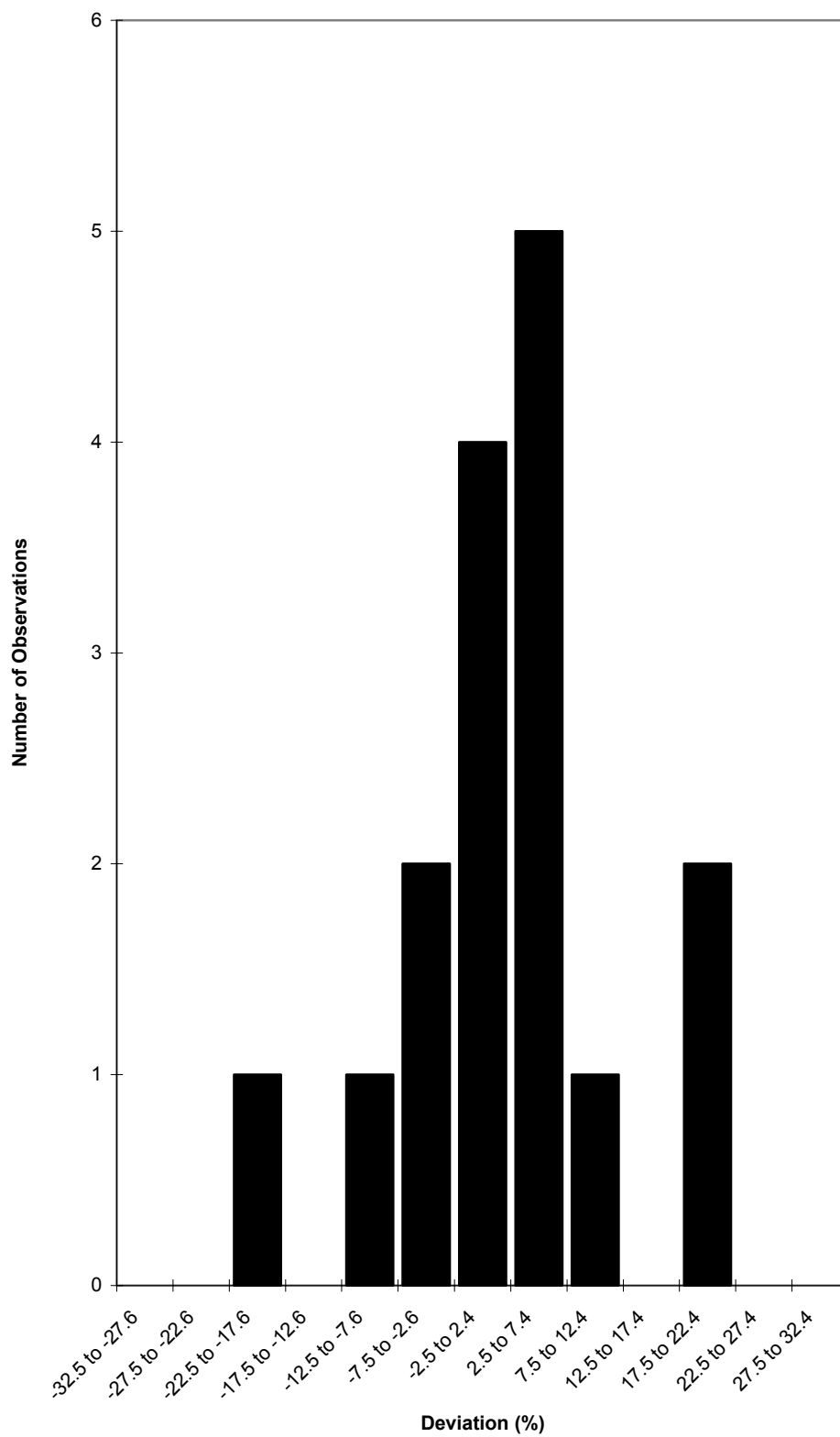
Figure 40 ^{60}Co low level results

Figure 41 - Reported ^{95}Zr results (low level)
(one outside limit of plot)

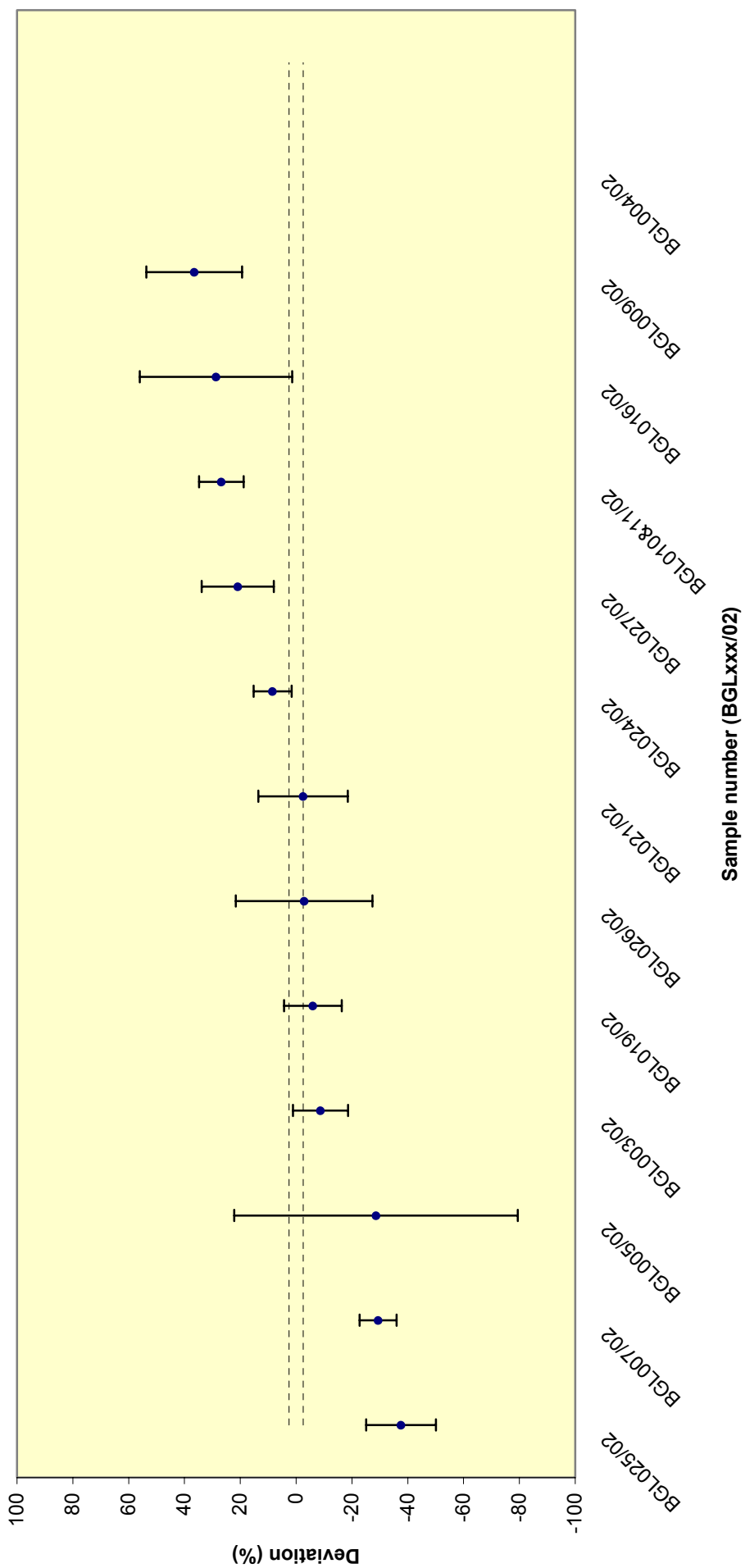


Figure 42 ^{95}Zr low level results
(Three outside limits of plot)

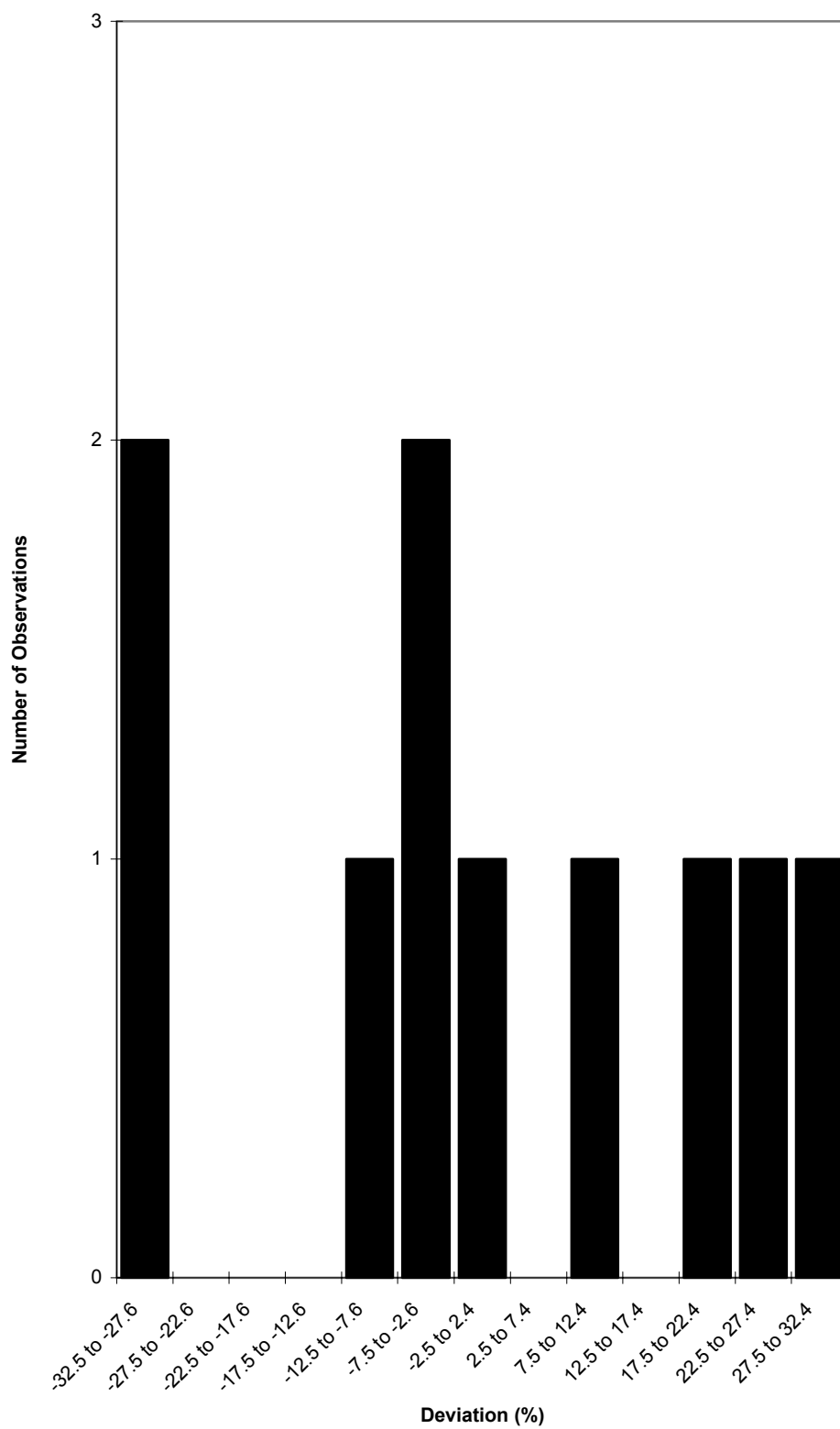


Figure 43 - Reported ^{106}Ru results (low level)

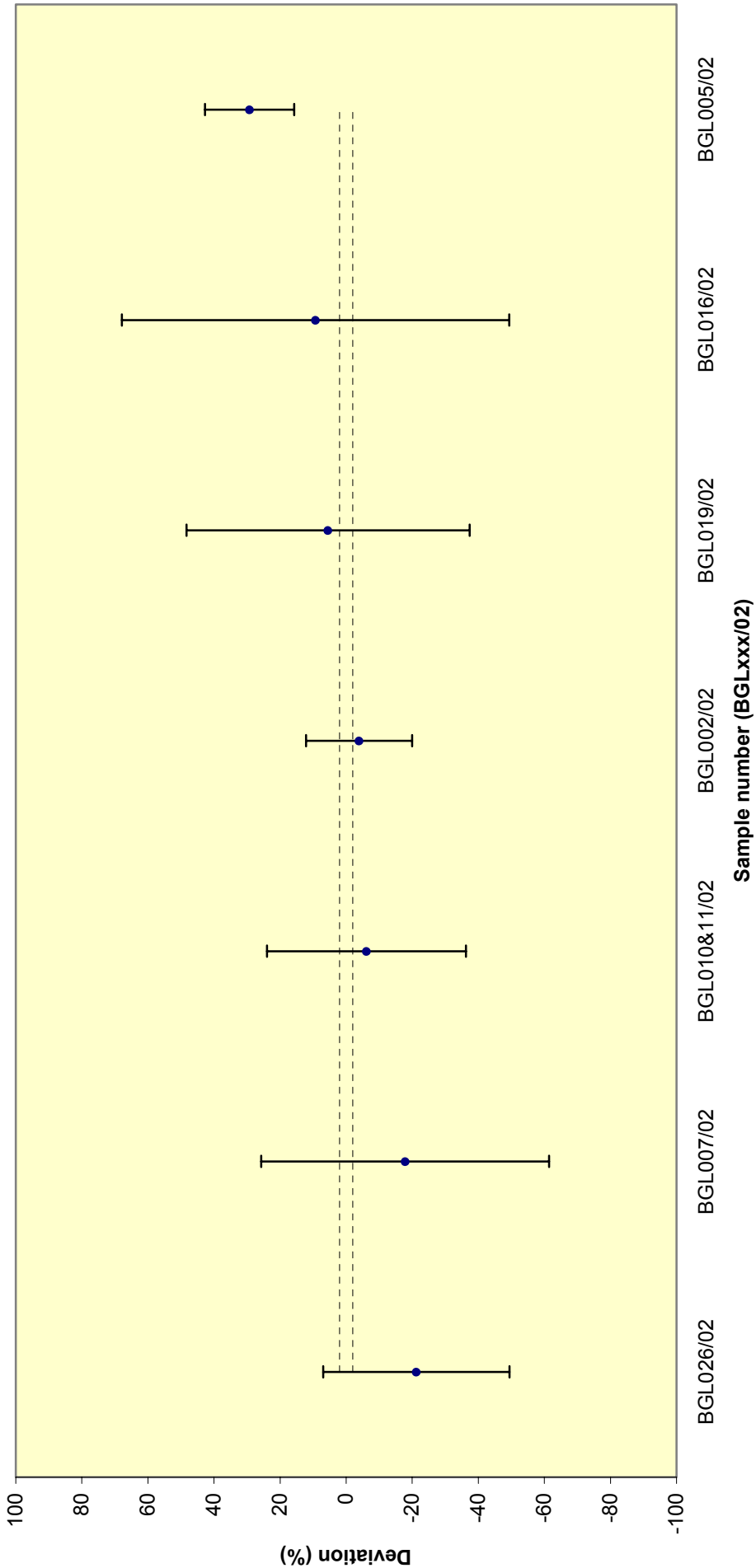


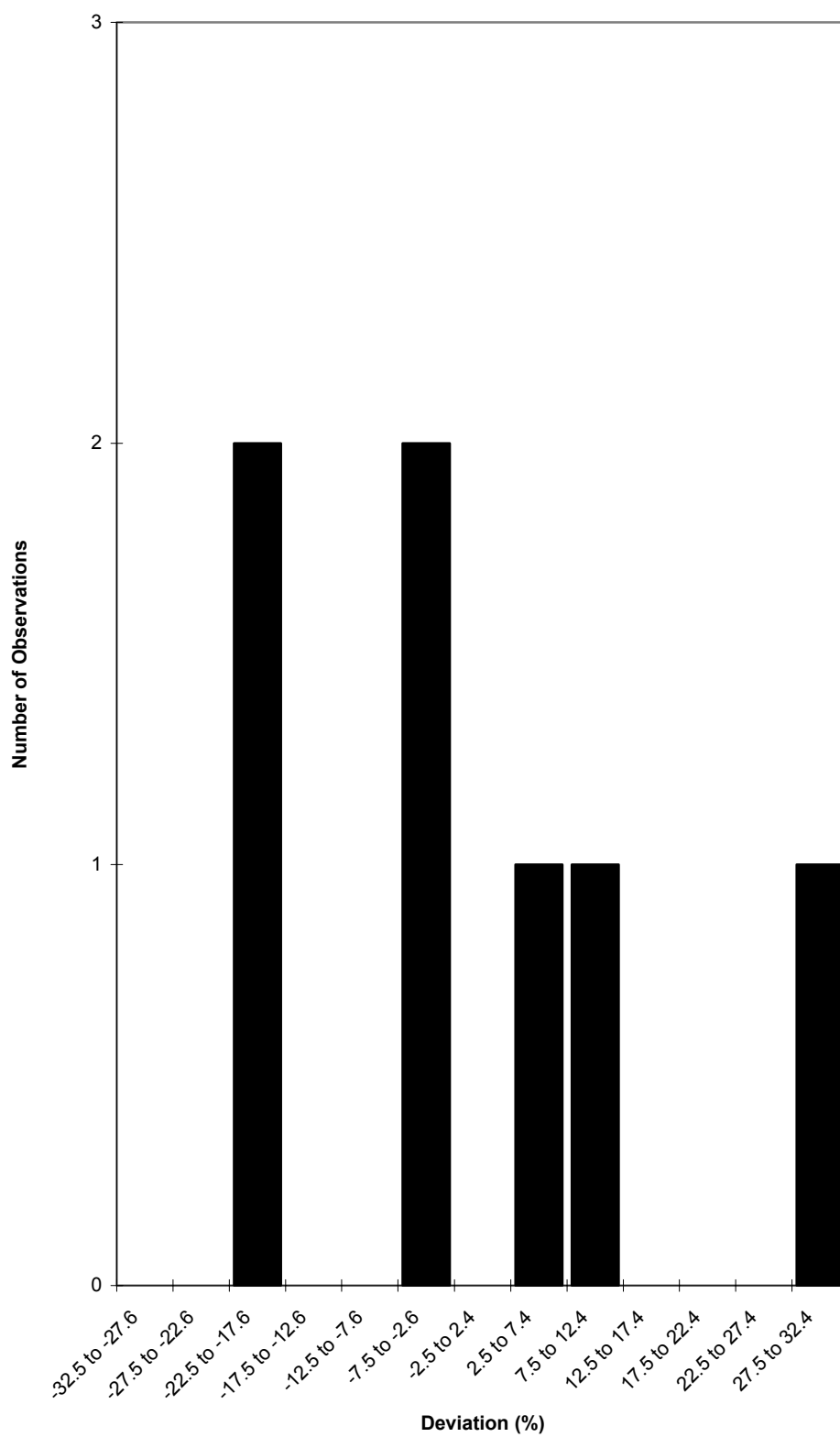
Figure 44 ^{106}Ru low level results

Figure 45 - Reported ^{134}Cs results (low level)

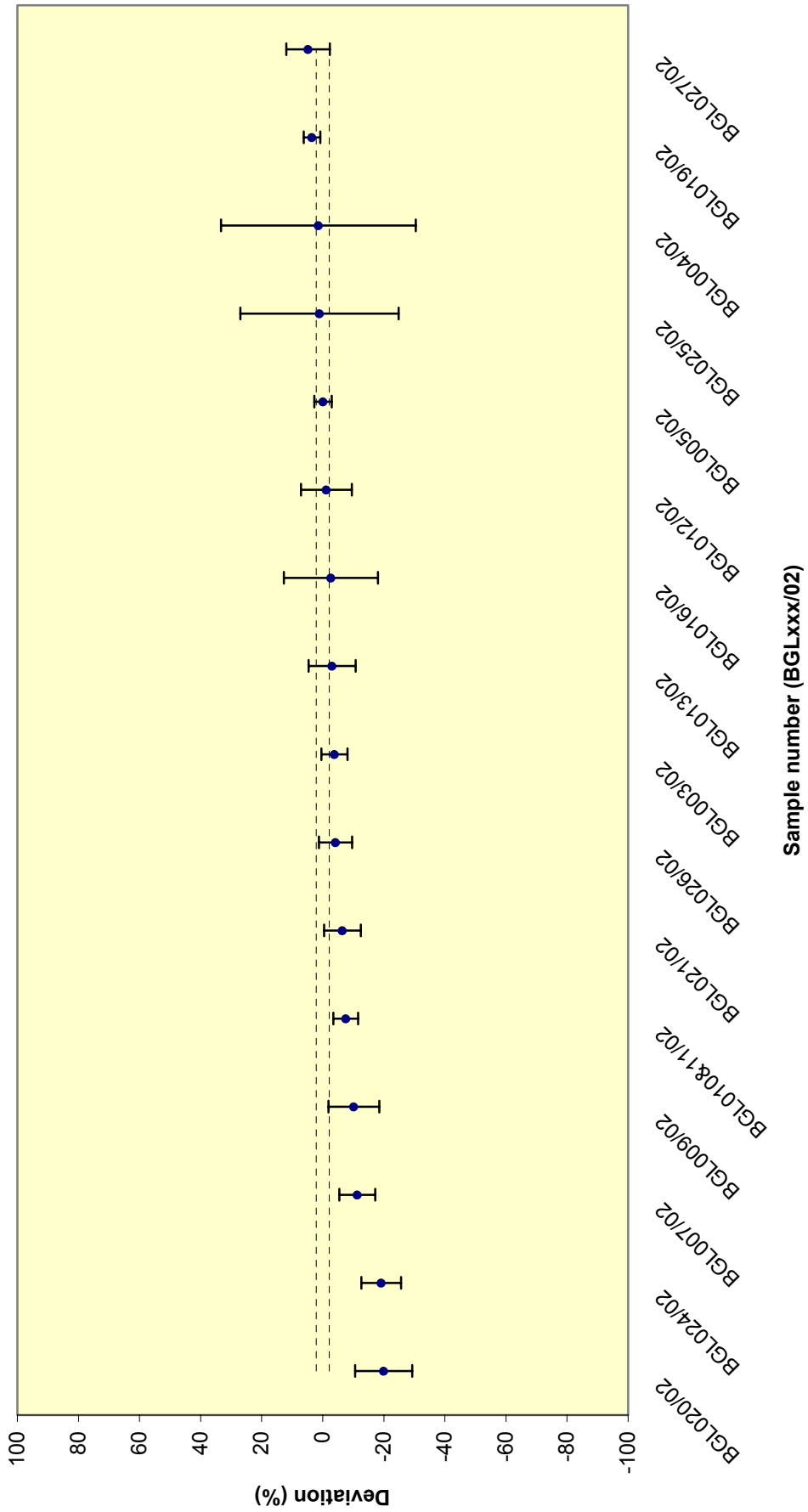


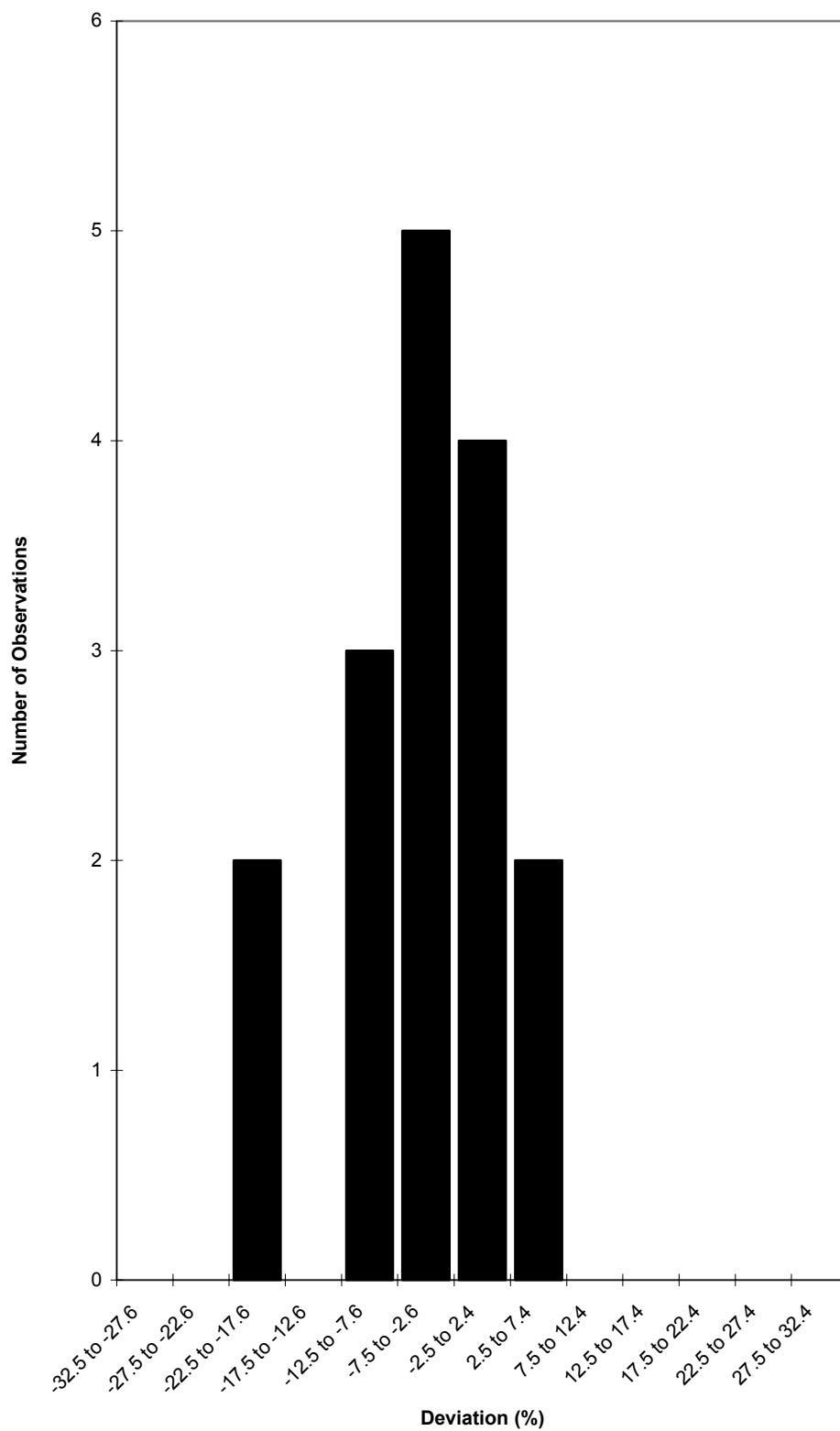
Figure 46 ^{134}Cs low level results

Figure 47 - Reported ^{137}Cs results (low level)

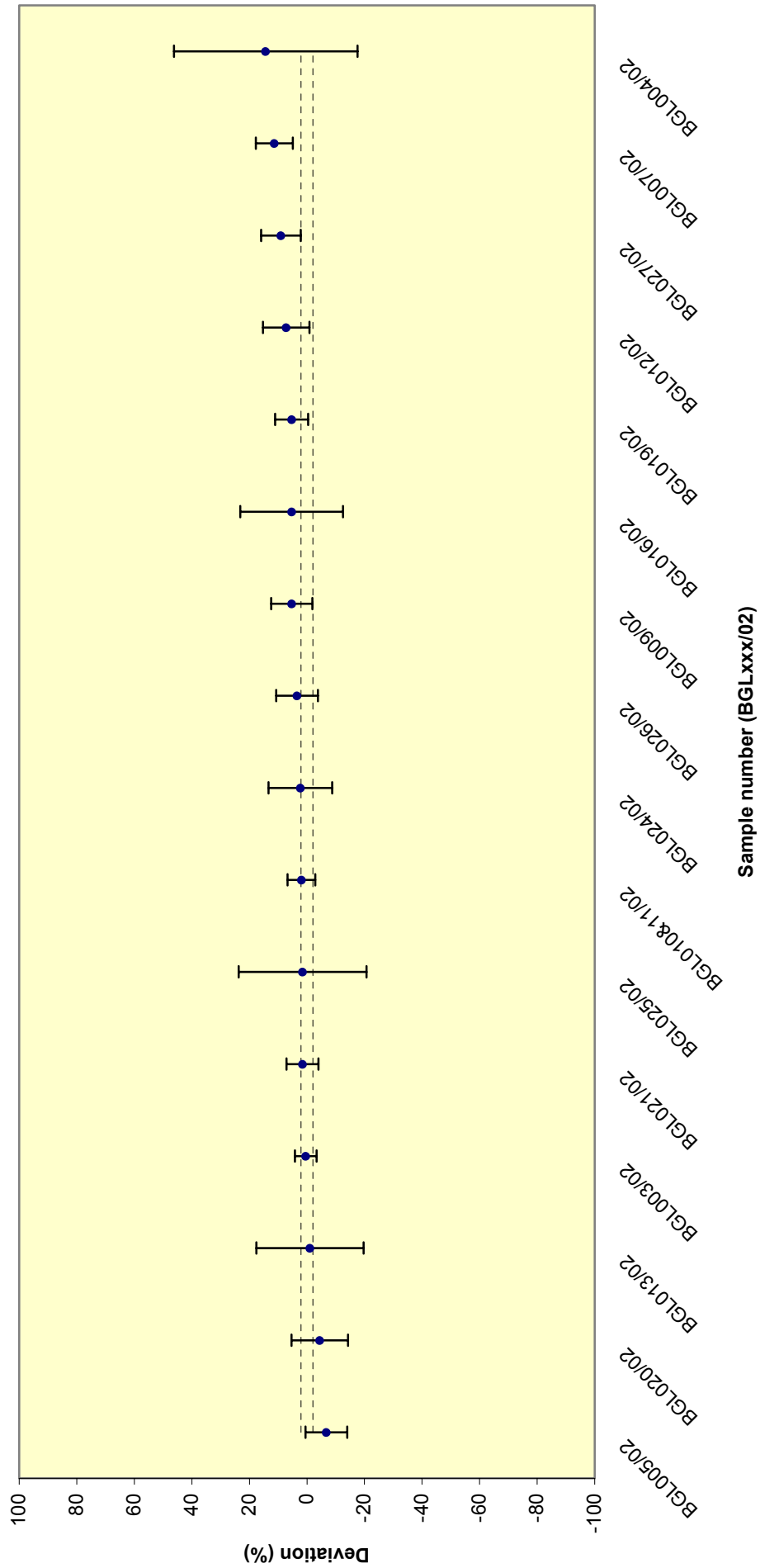


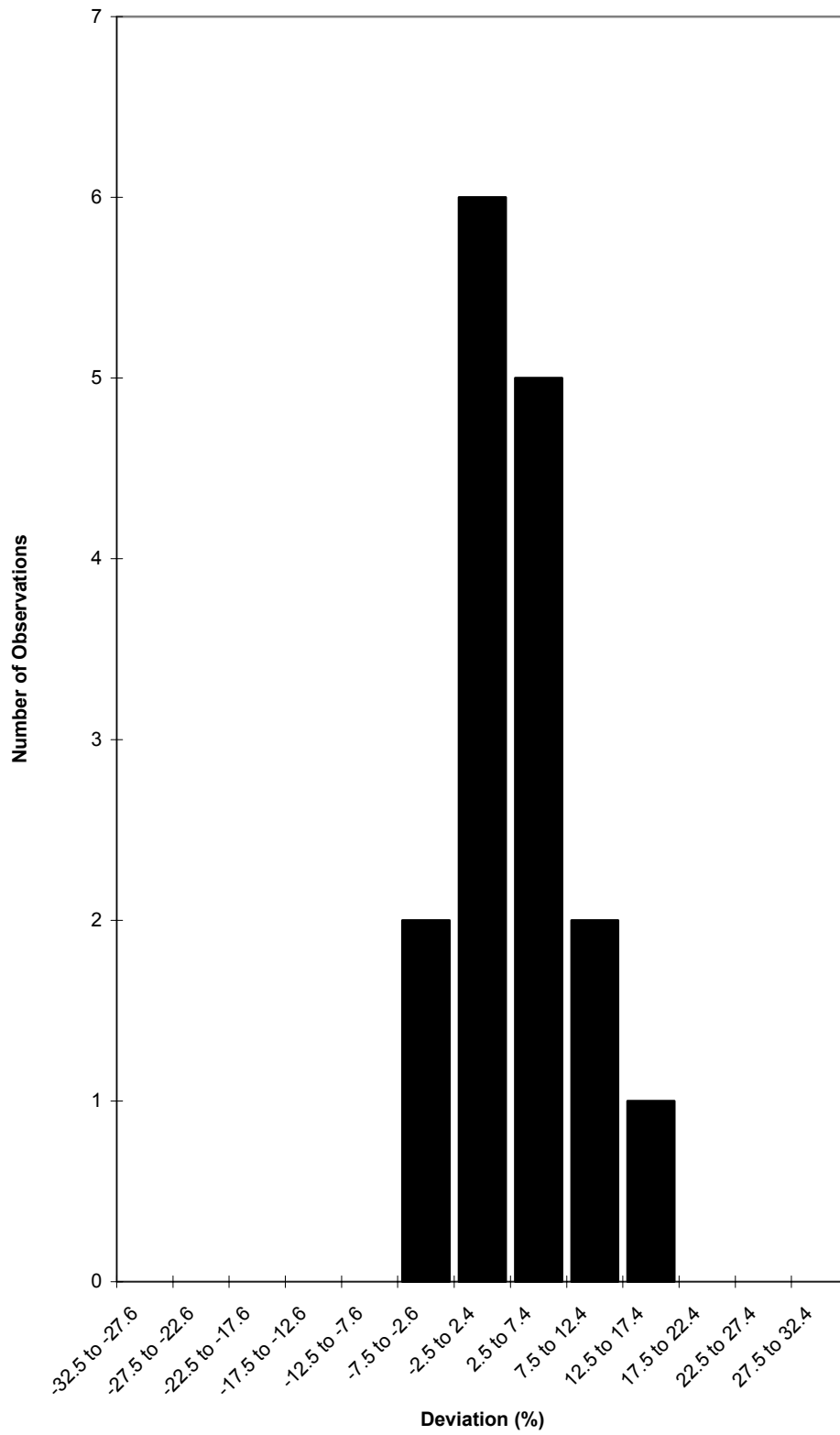
Figure 48 ^{137}Cs low level results

Figure 49 - Reported ^{154}Eu results (low level)

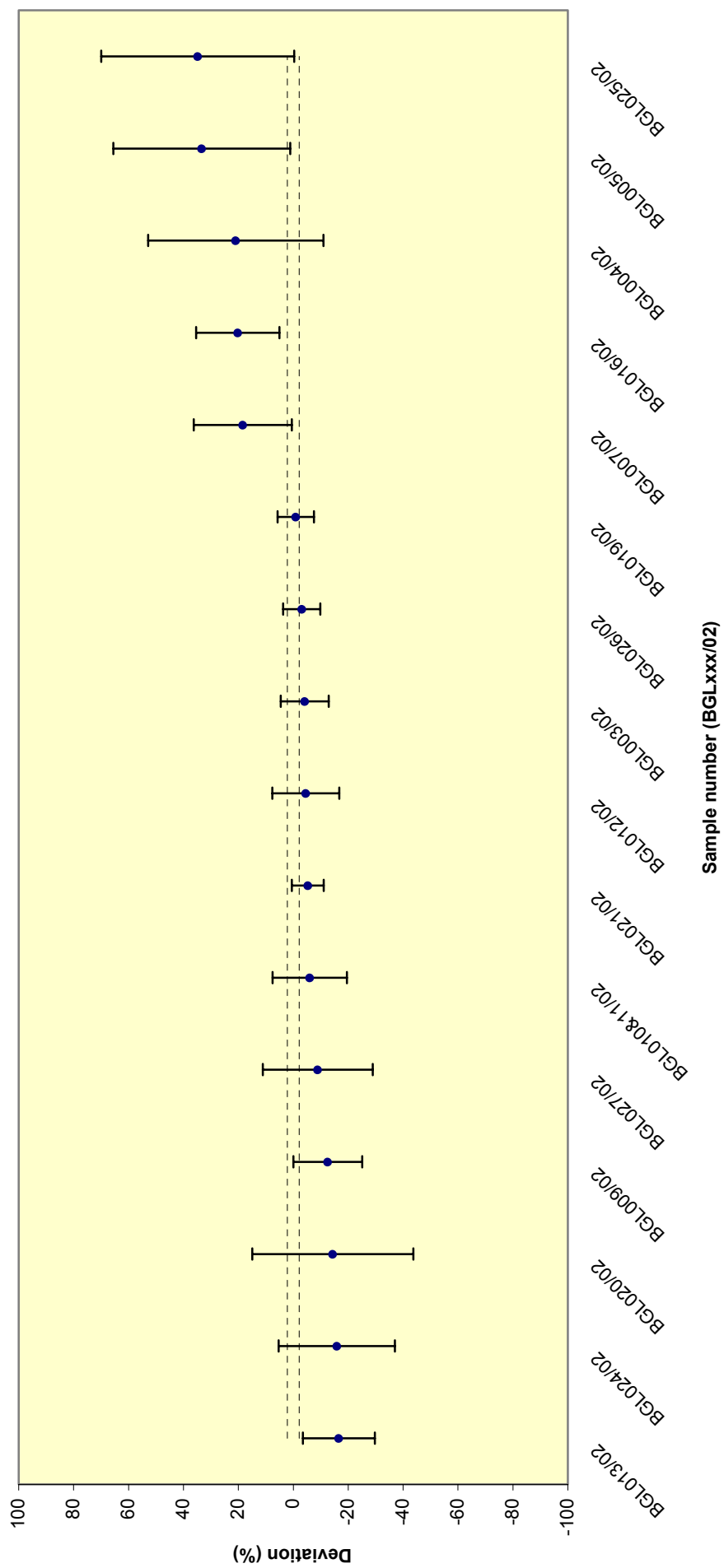


Figure 50 ^{154}Eu low level results
(Two outside limits of plot)

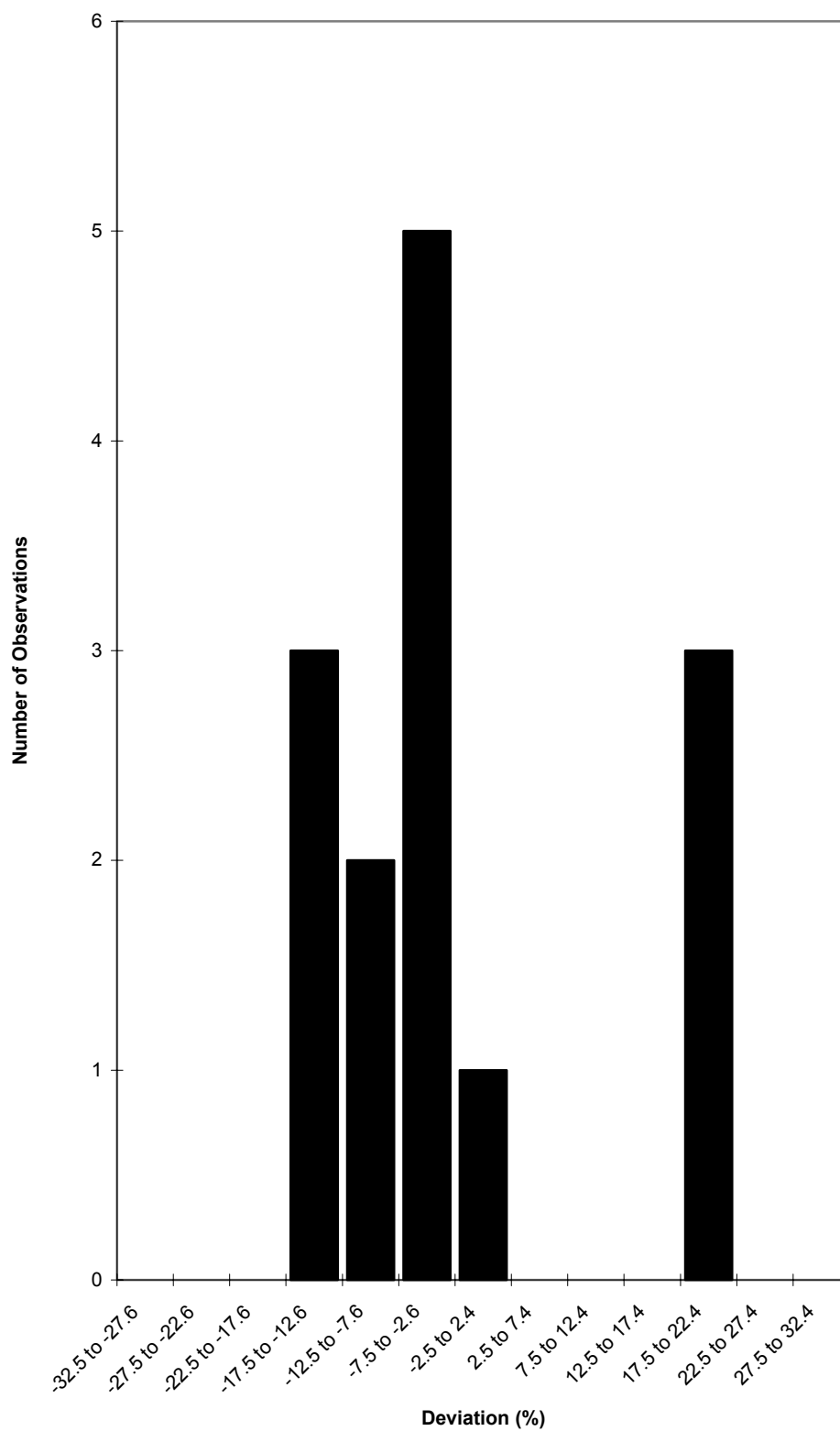


Figure 51 - Reported ^{155}Eu results (low level)

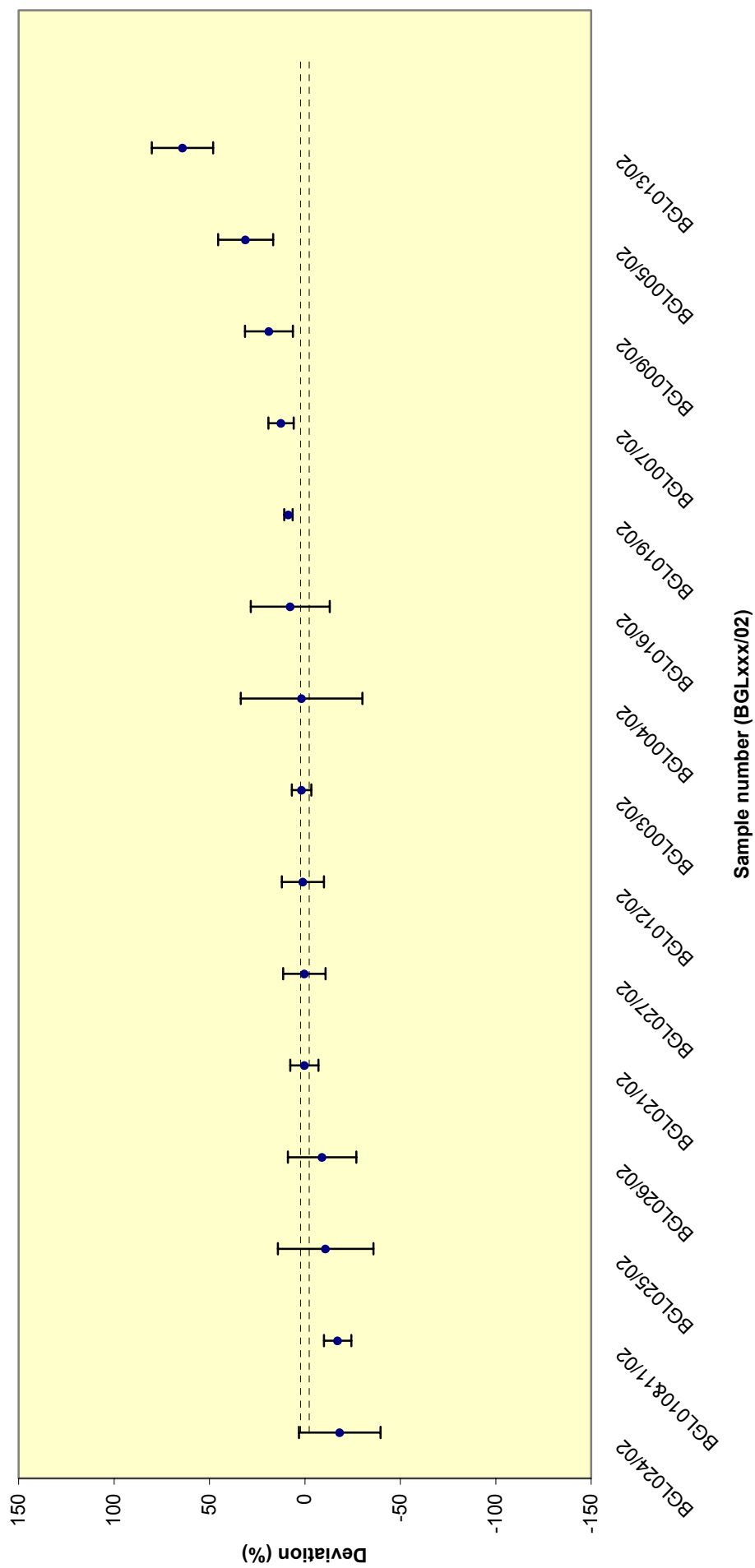


Figure 52 ^{155}Eu low level results
(One outside limits of plot)

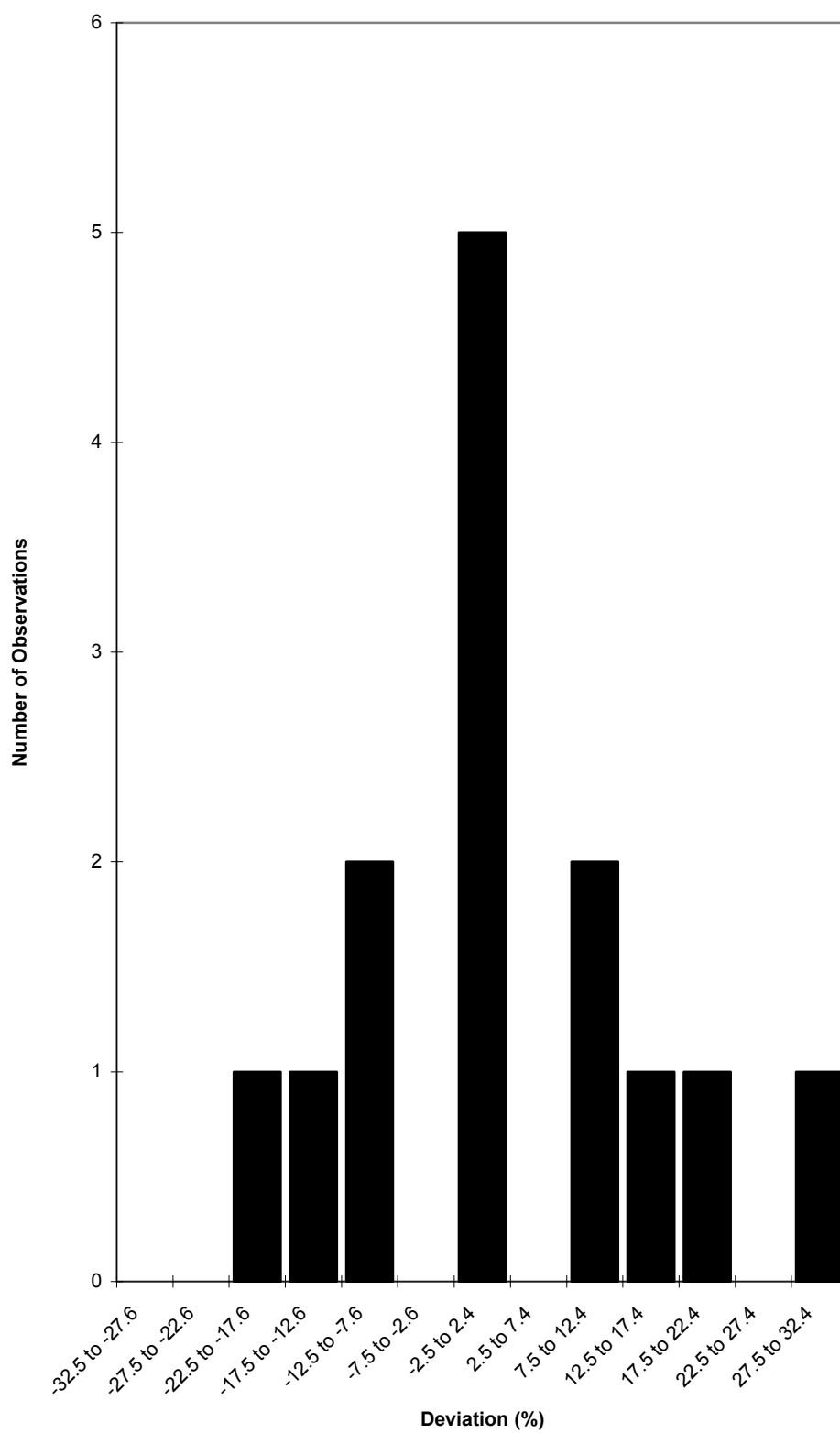


Figure 53 - Reported ^{22}Na results (high level)

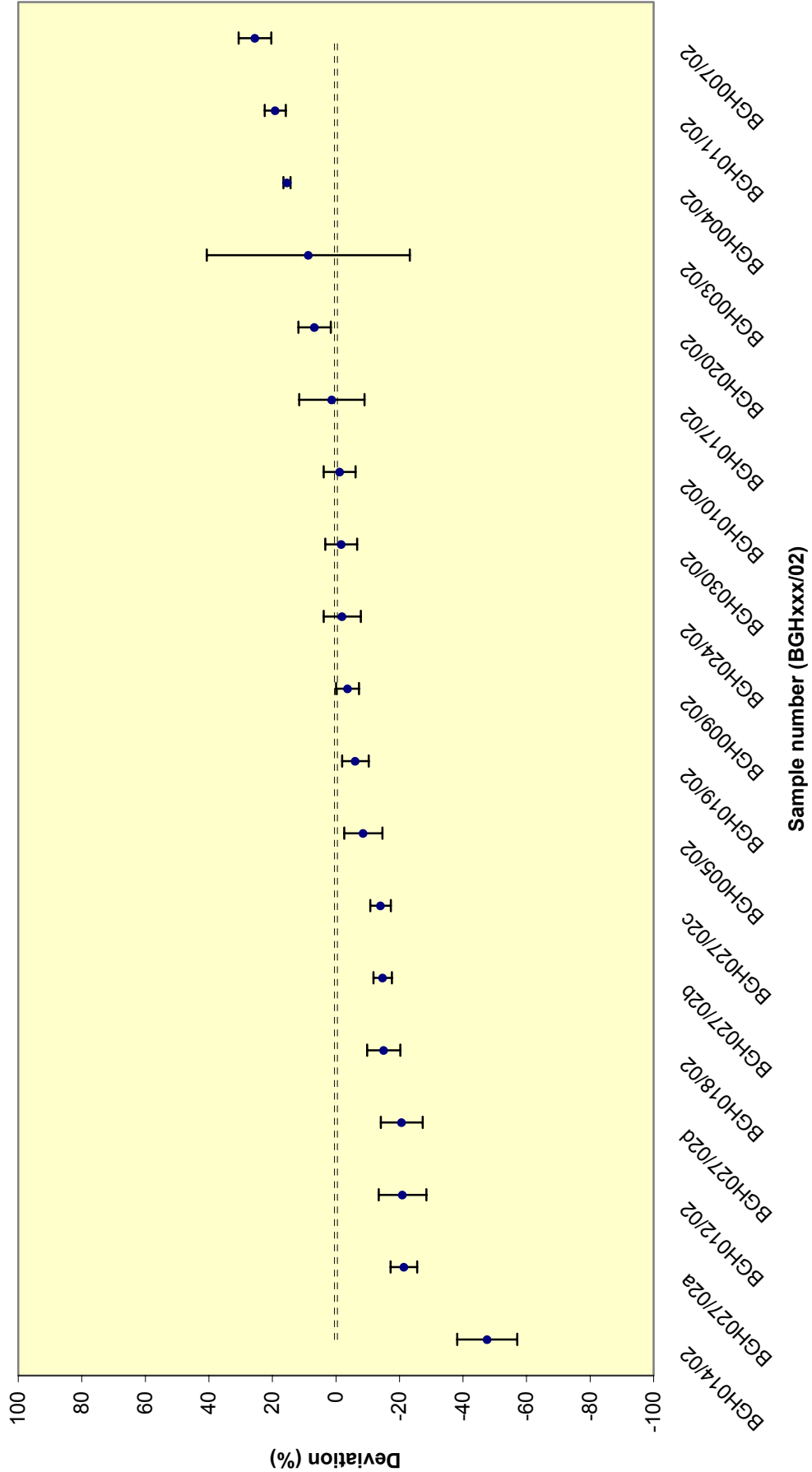


Figure 54 ^{22}Na high level results
(One outside limits of plot)

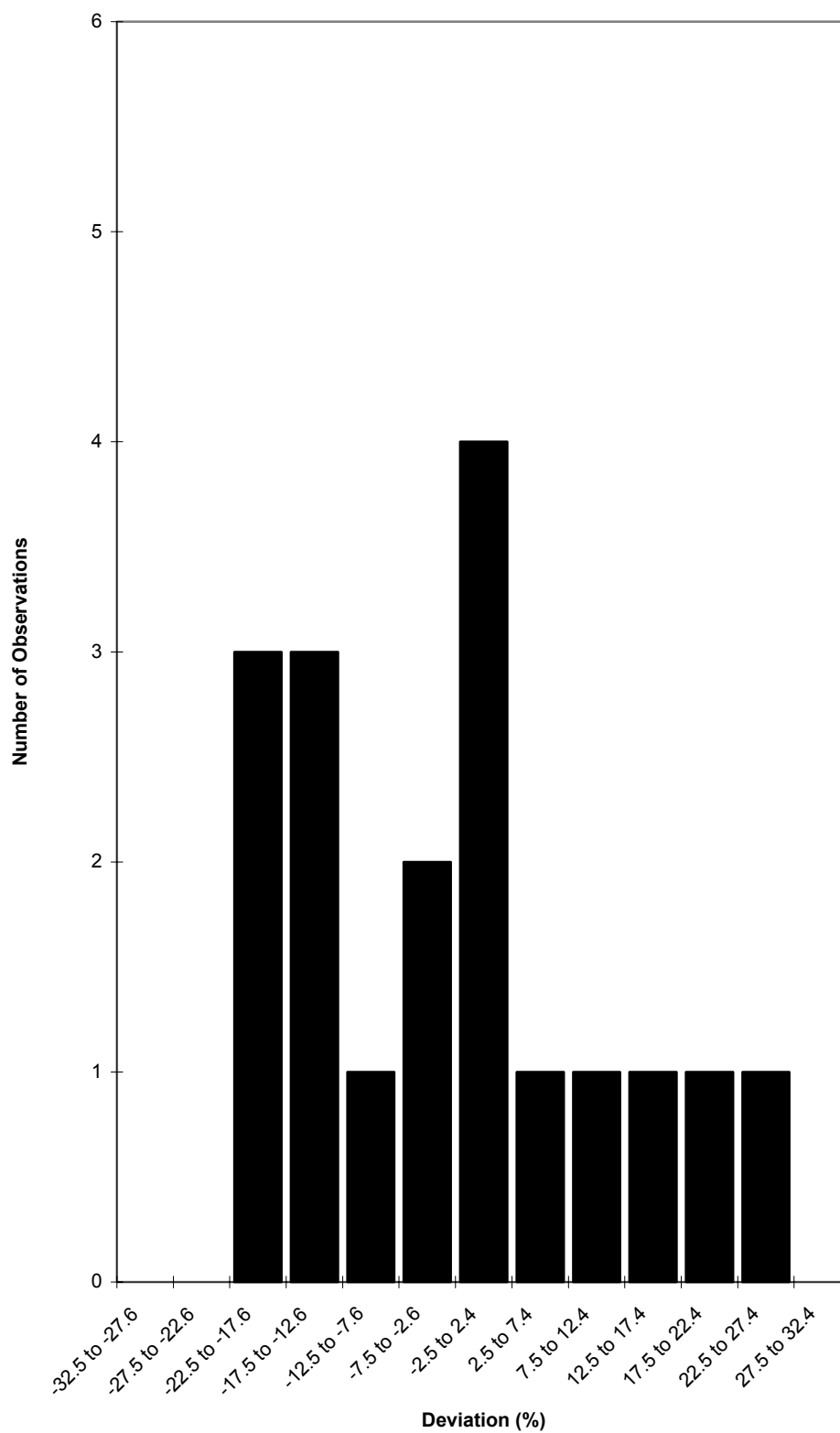


Figure 55 - Reported ^{57}Co results (high level)

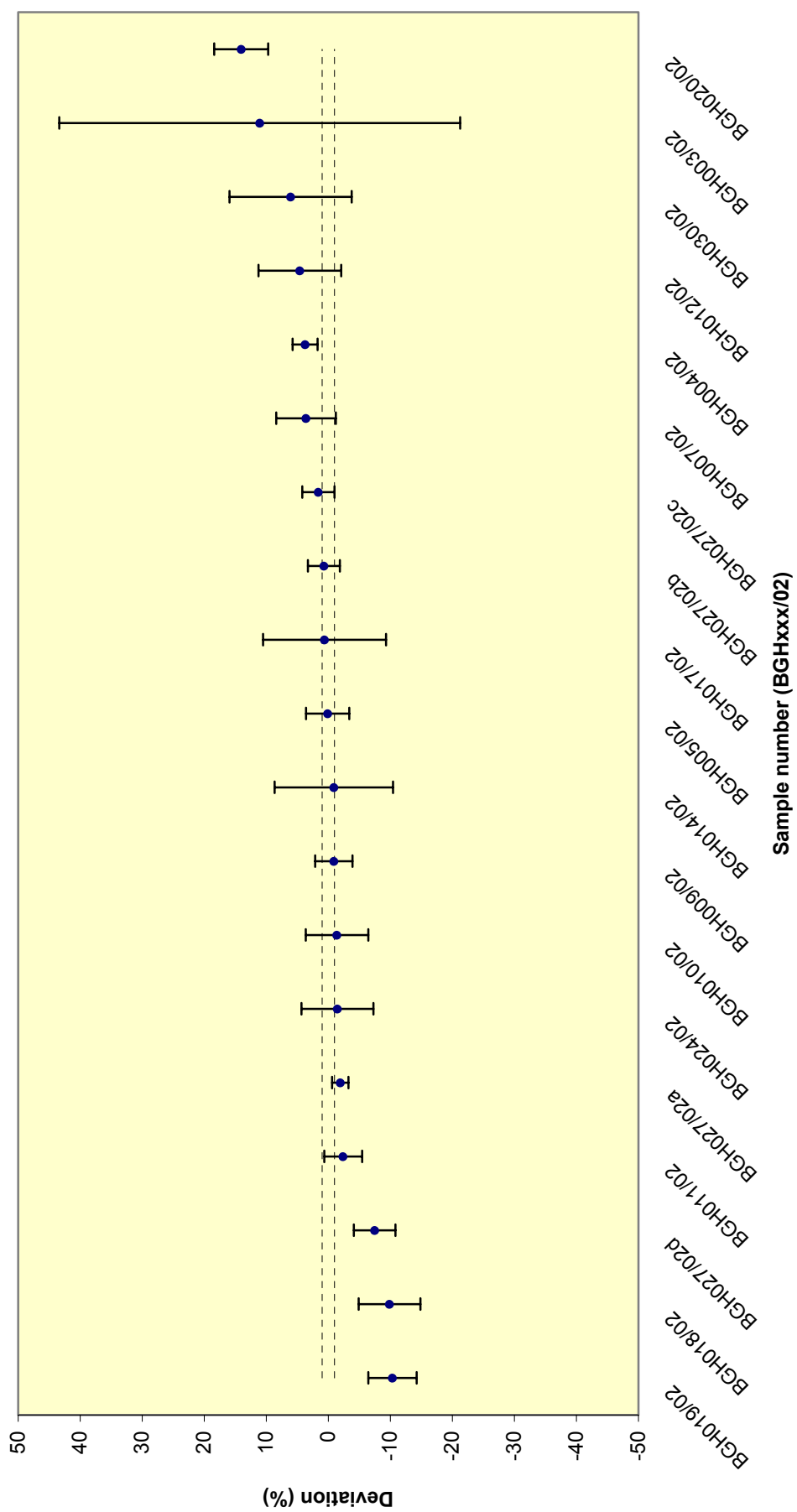


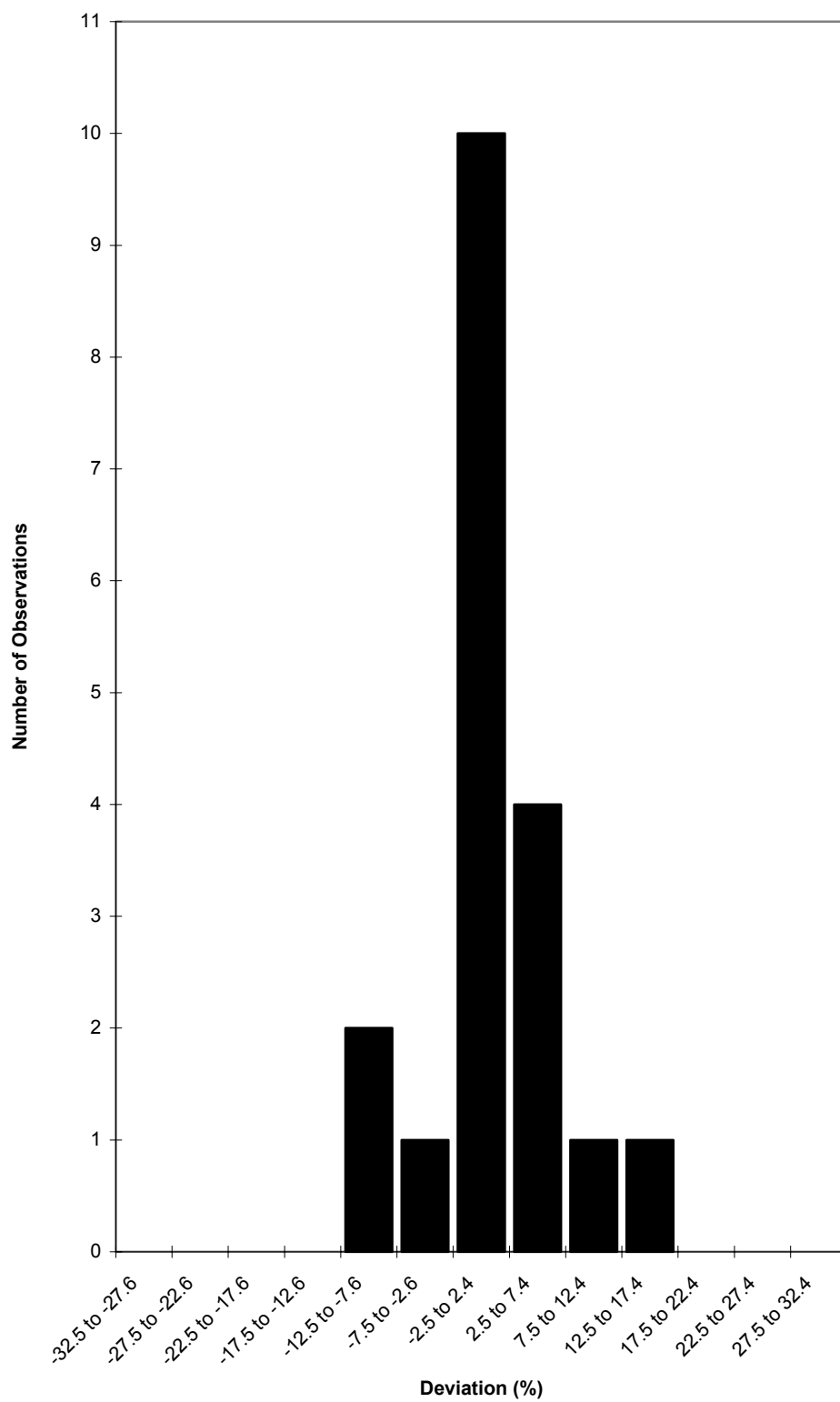
Figure 56 ^{57}Co high level results

Figure 57 - Reported ^{60}Co results (high level)

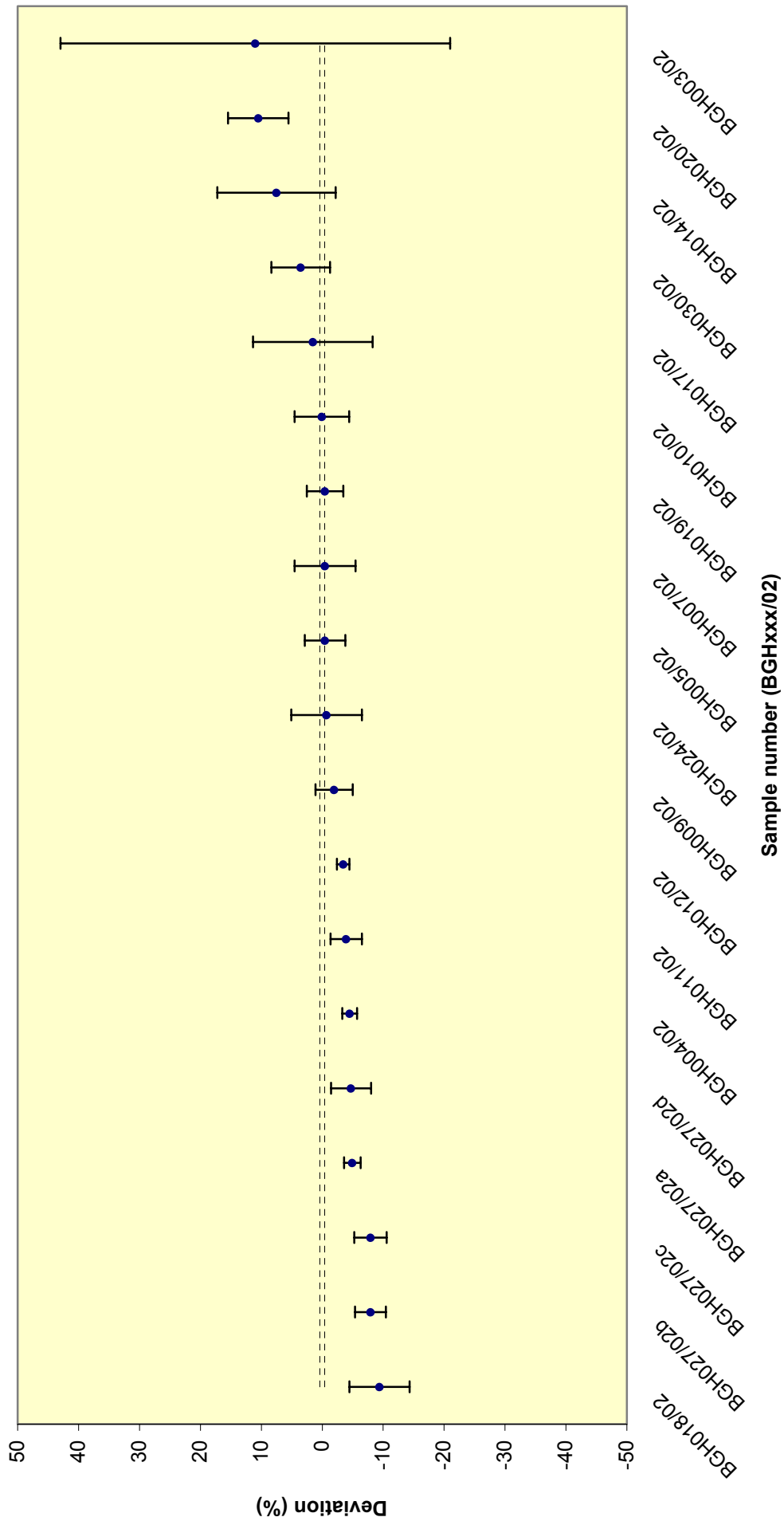


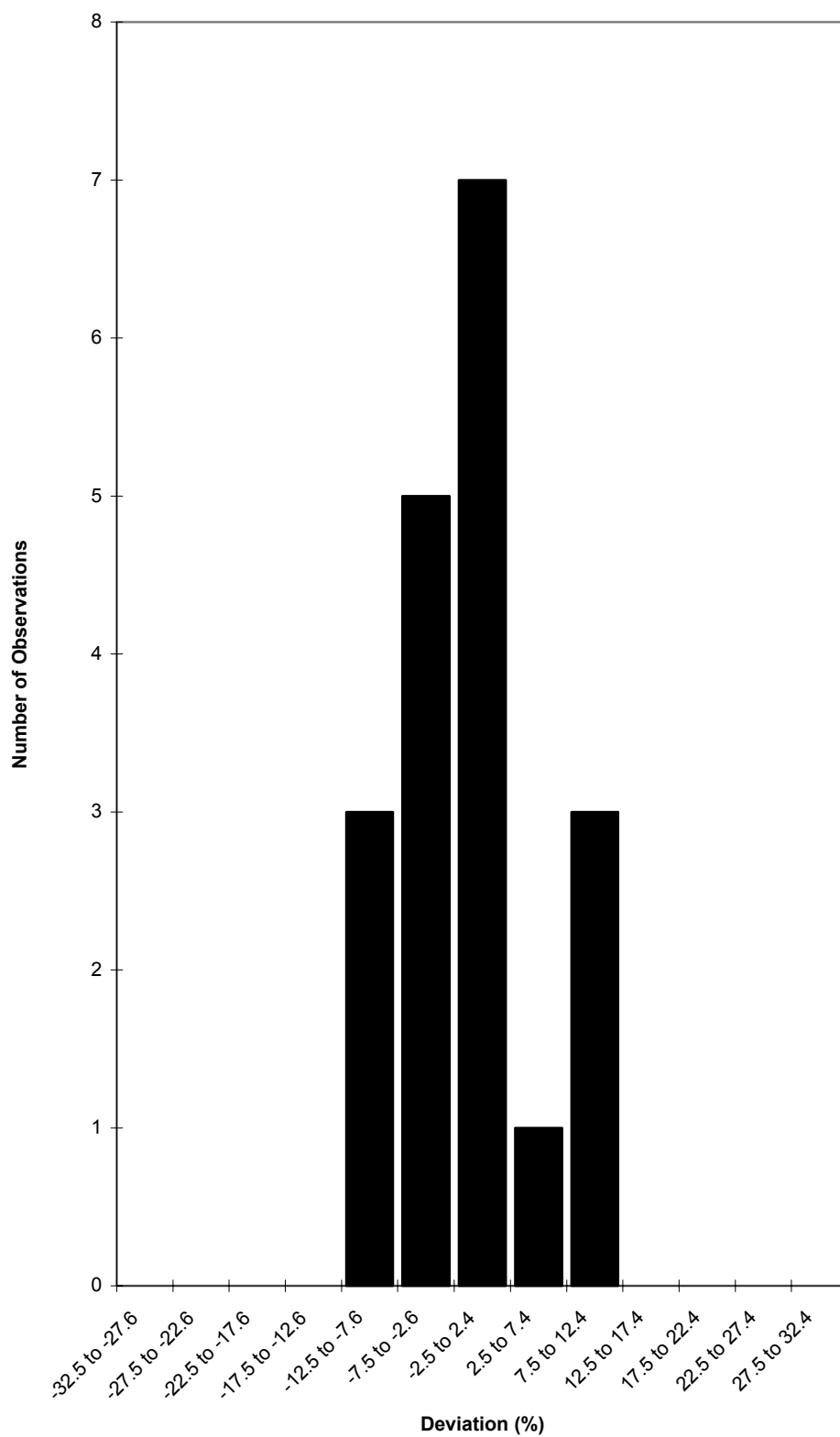
Figure 58 ^{60}Co high level results

Figure 59 - Reported ^{95}Zr results (high level)

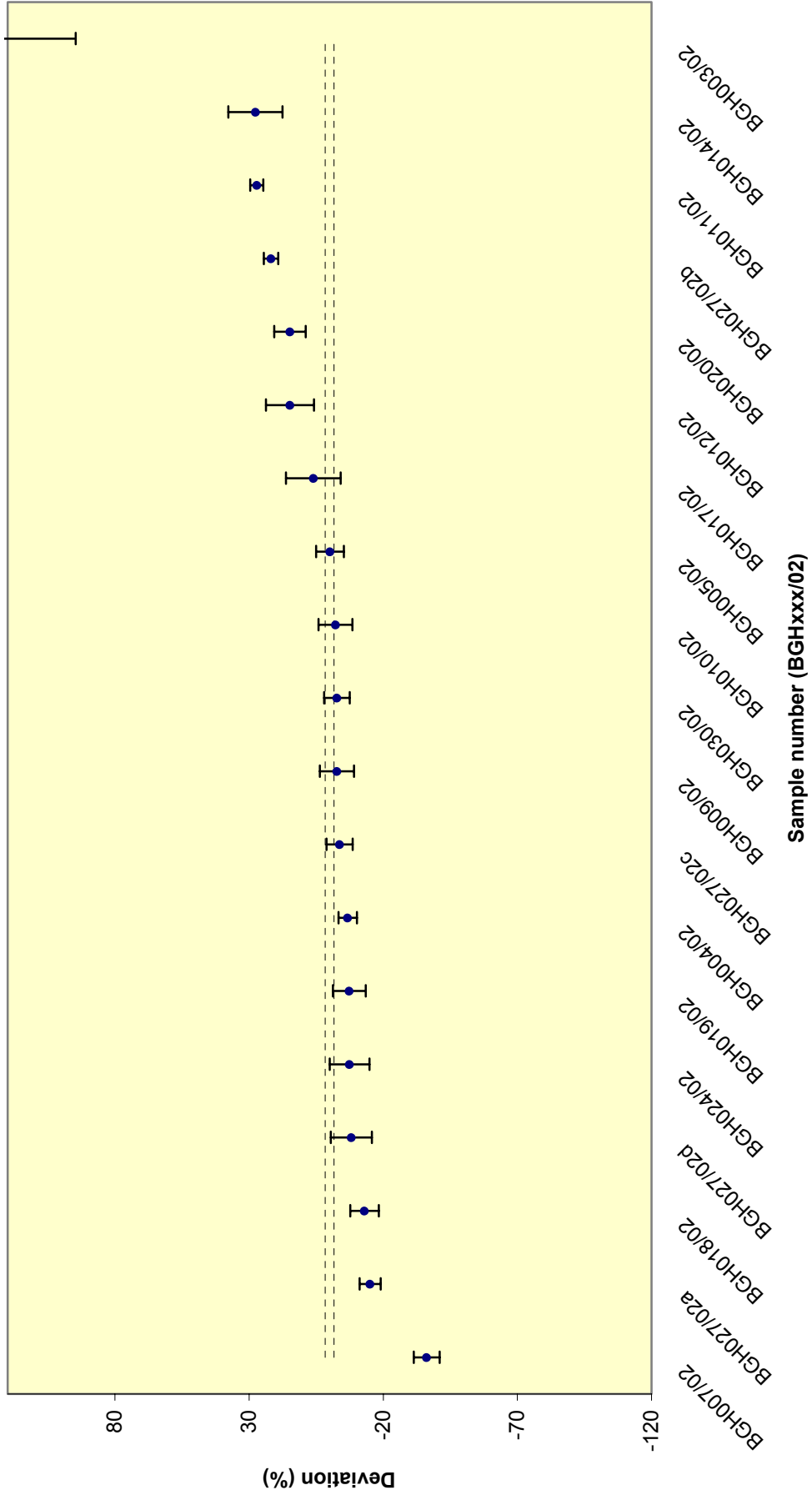


Figure 60 ^{95}Zr high level results
(Two outside limits of plot)

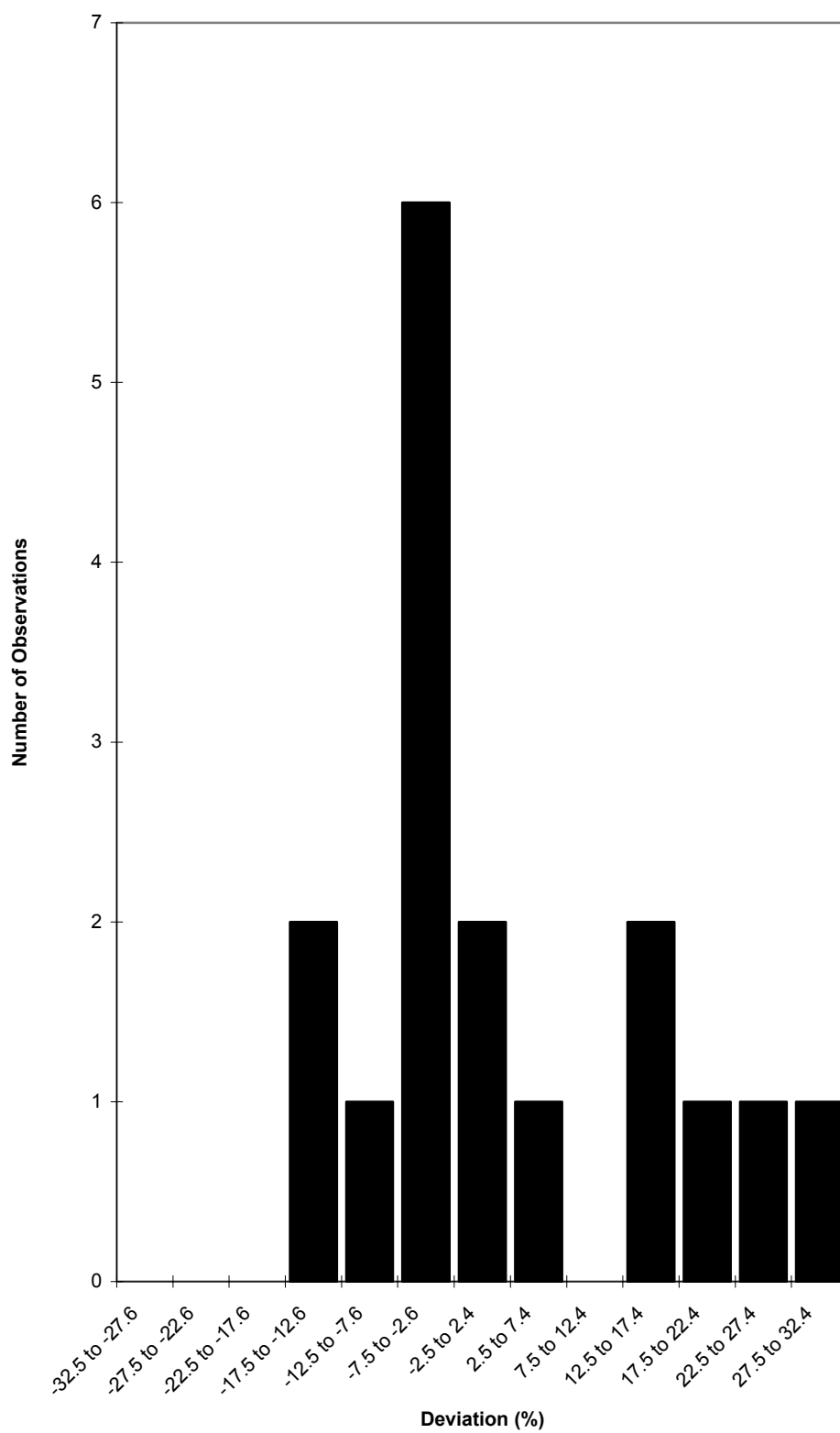


Figure 61 - Reported ^{106}Ru results (high level)

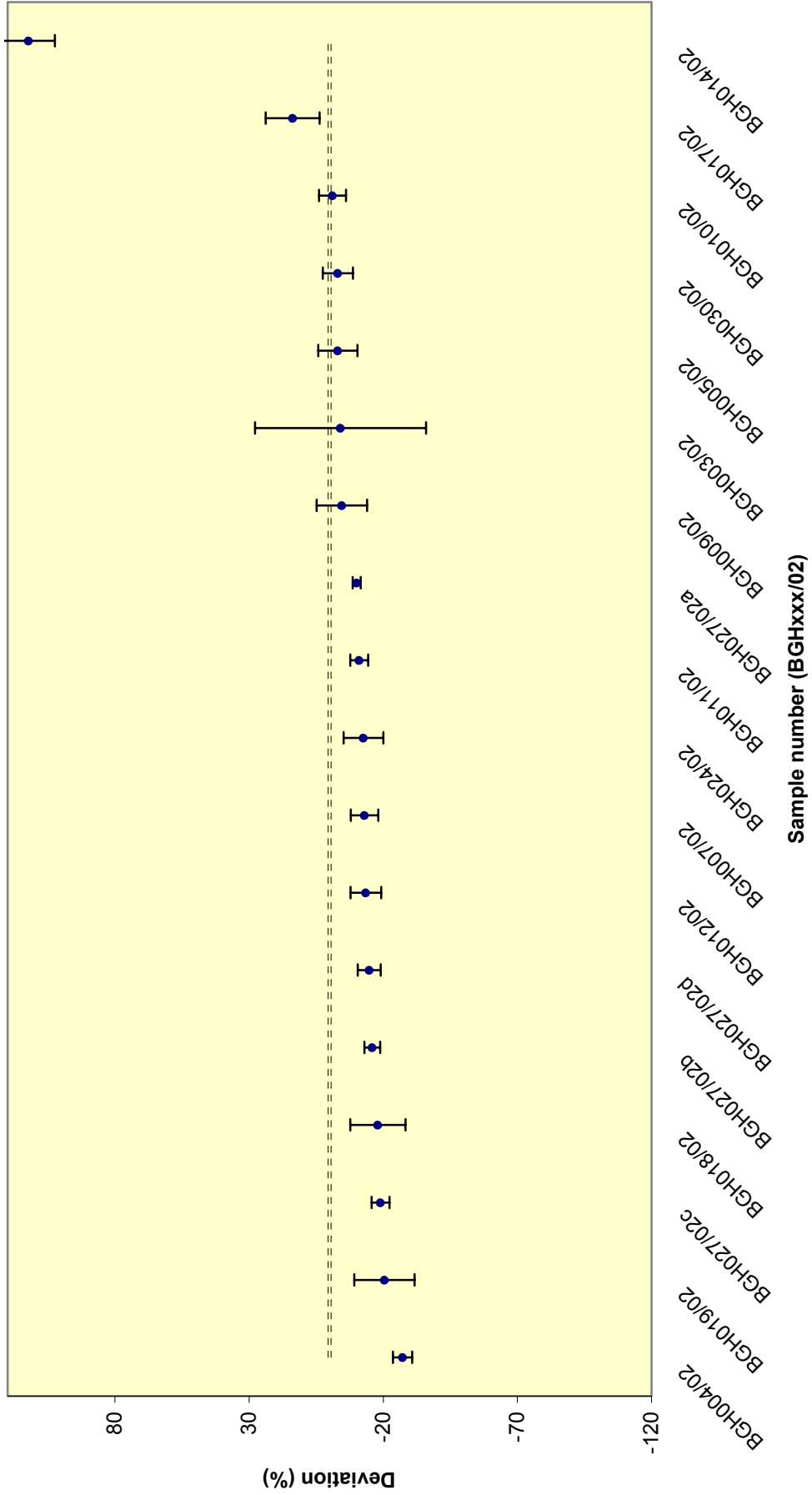


Figure 62 ^{106}Ru high level results
(One outside limits of plot)

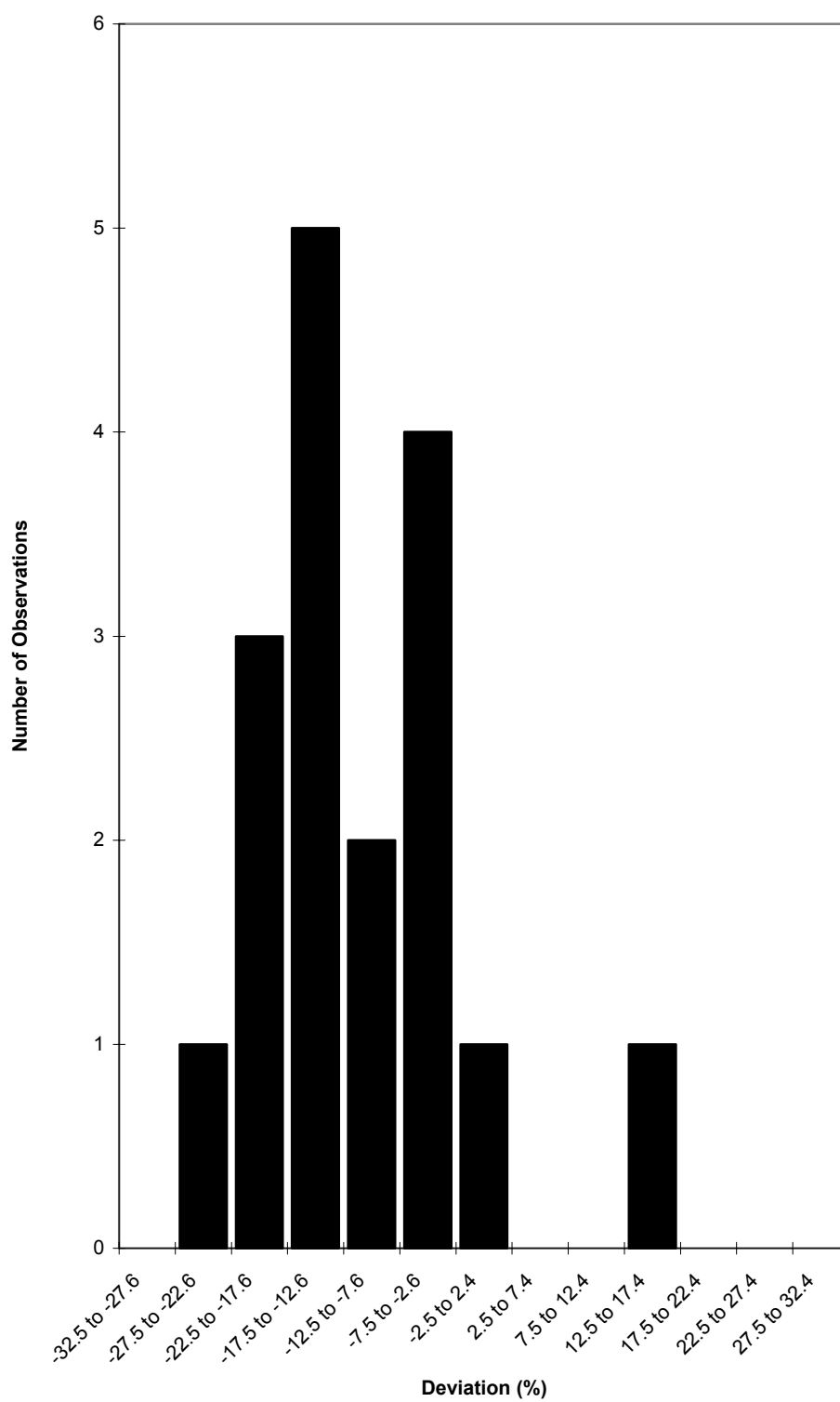


Figure 63 - Reported ^{134}Cs results (high level)

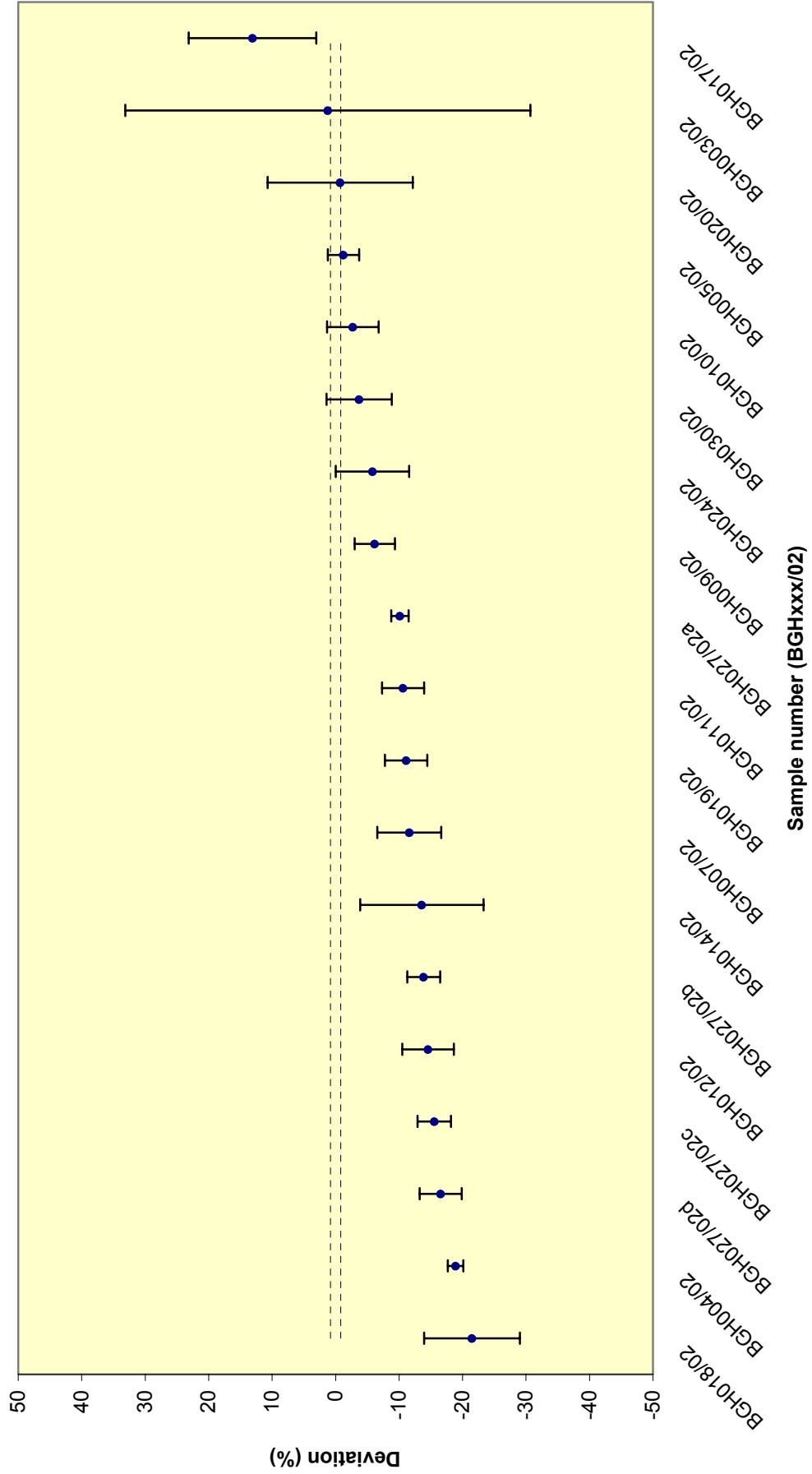


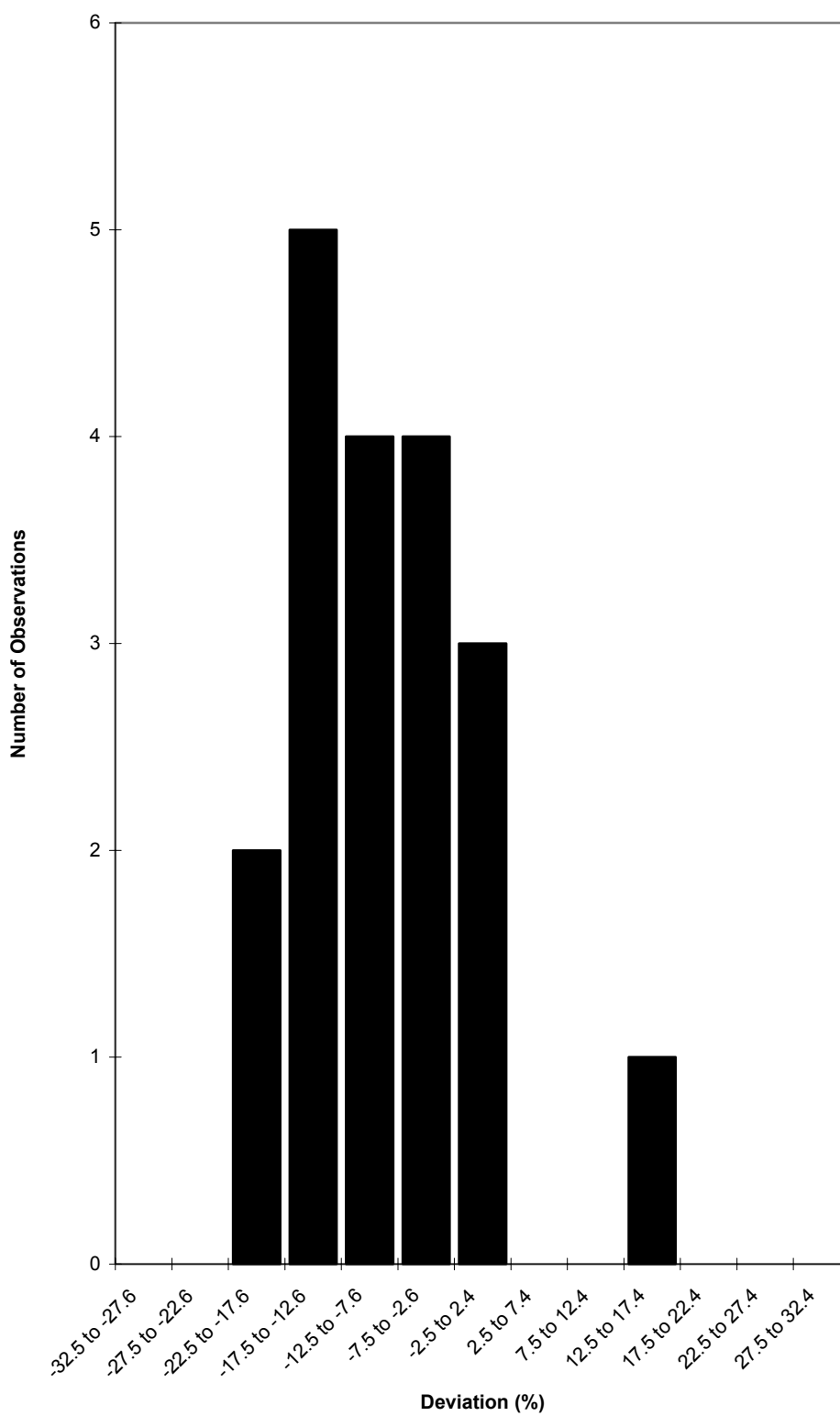
Figure 64 ^{134}Cs high level results

Figure 65 - Reported ^{137}Cs results (high level)

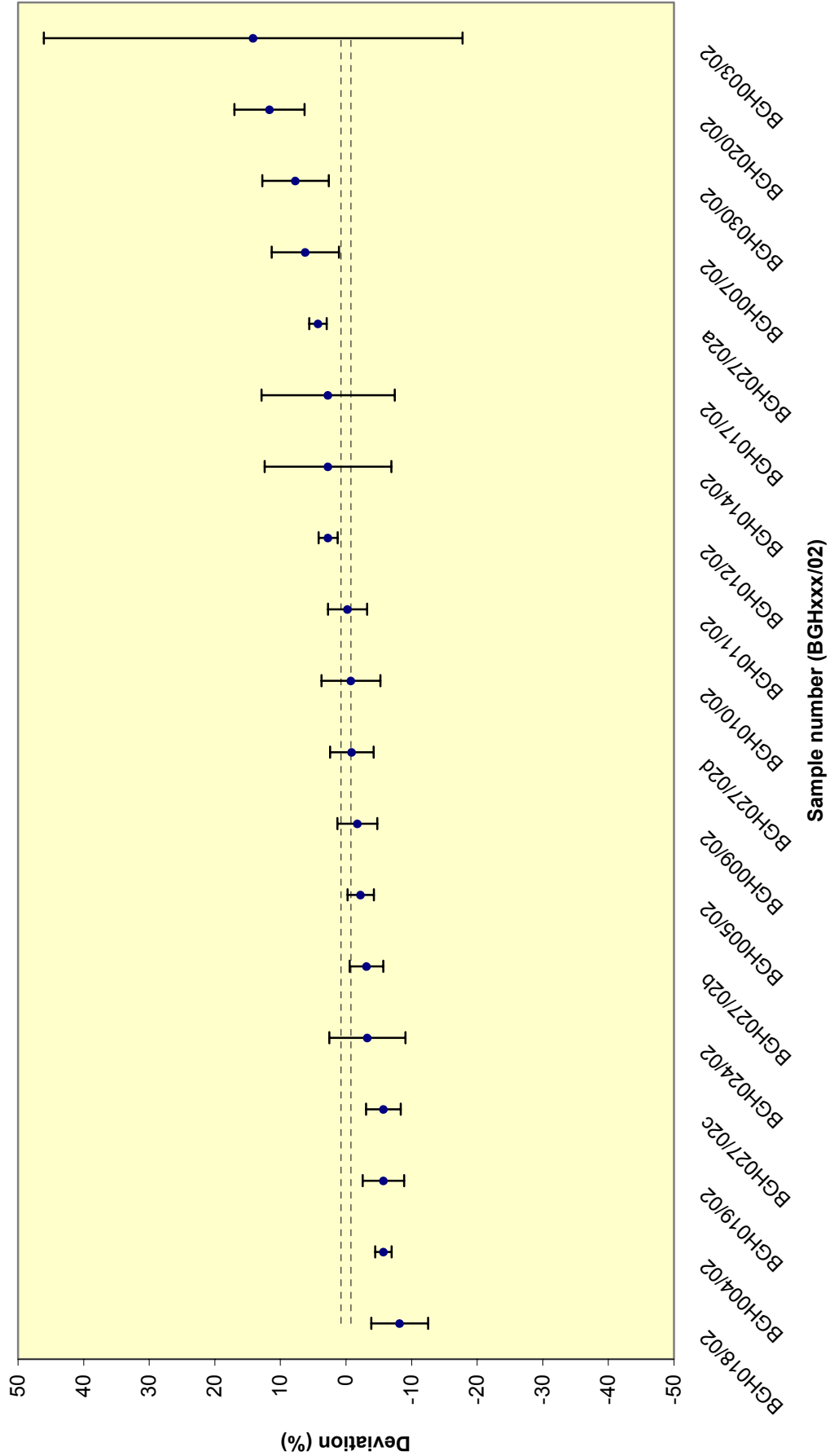


Figure 66 ^{137}Cs high level results
(One outside limits of plot)

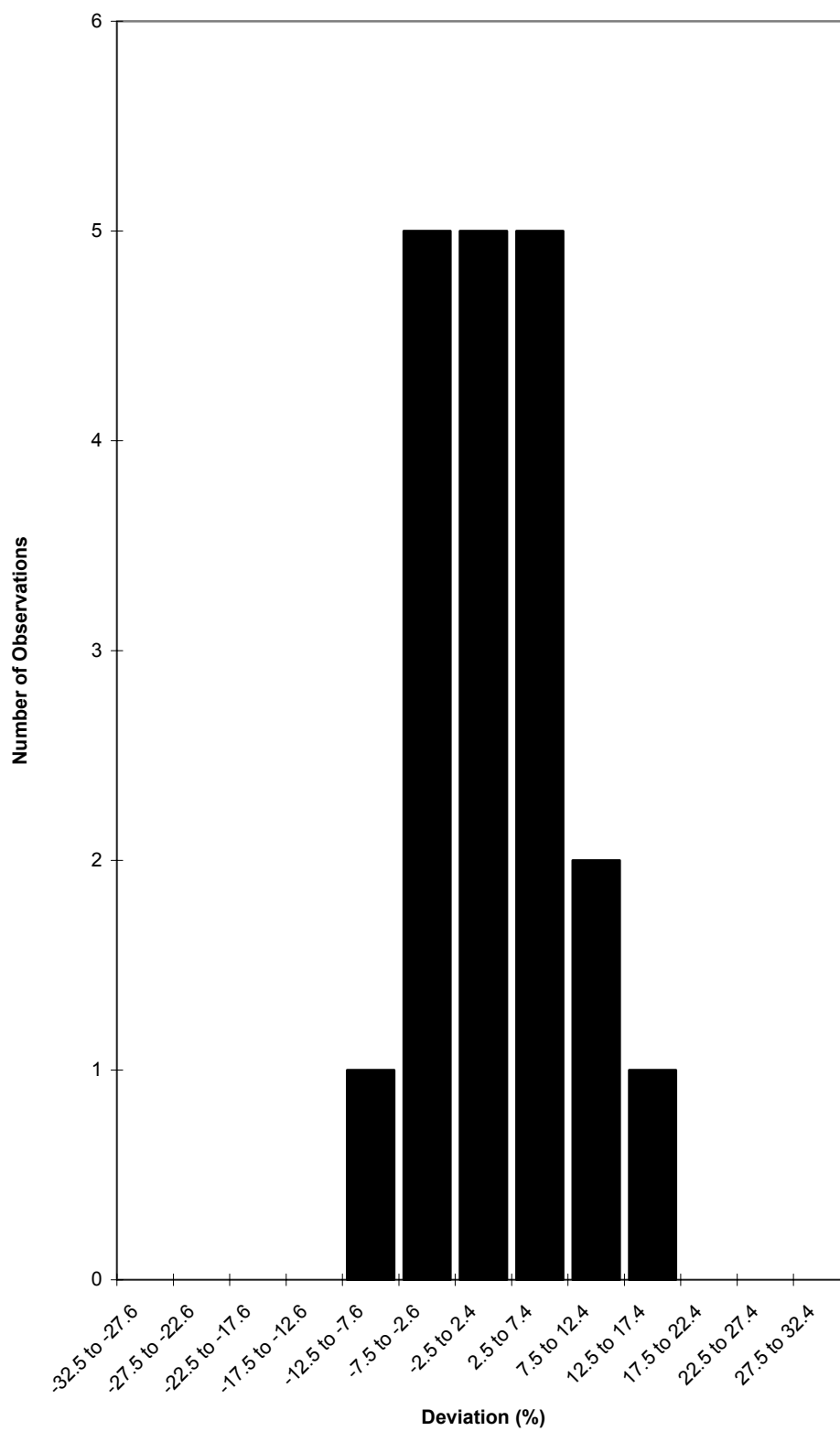


Figure 67 - Reported ^{154}Eu results (high level)

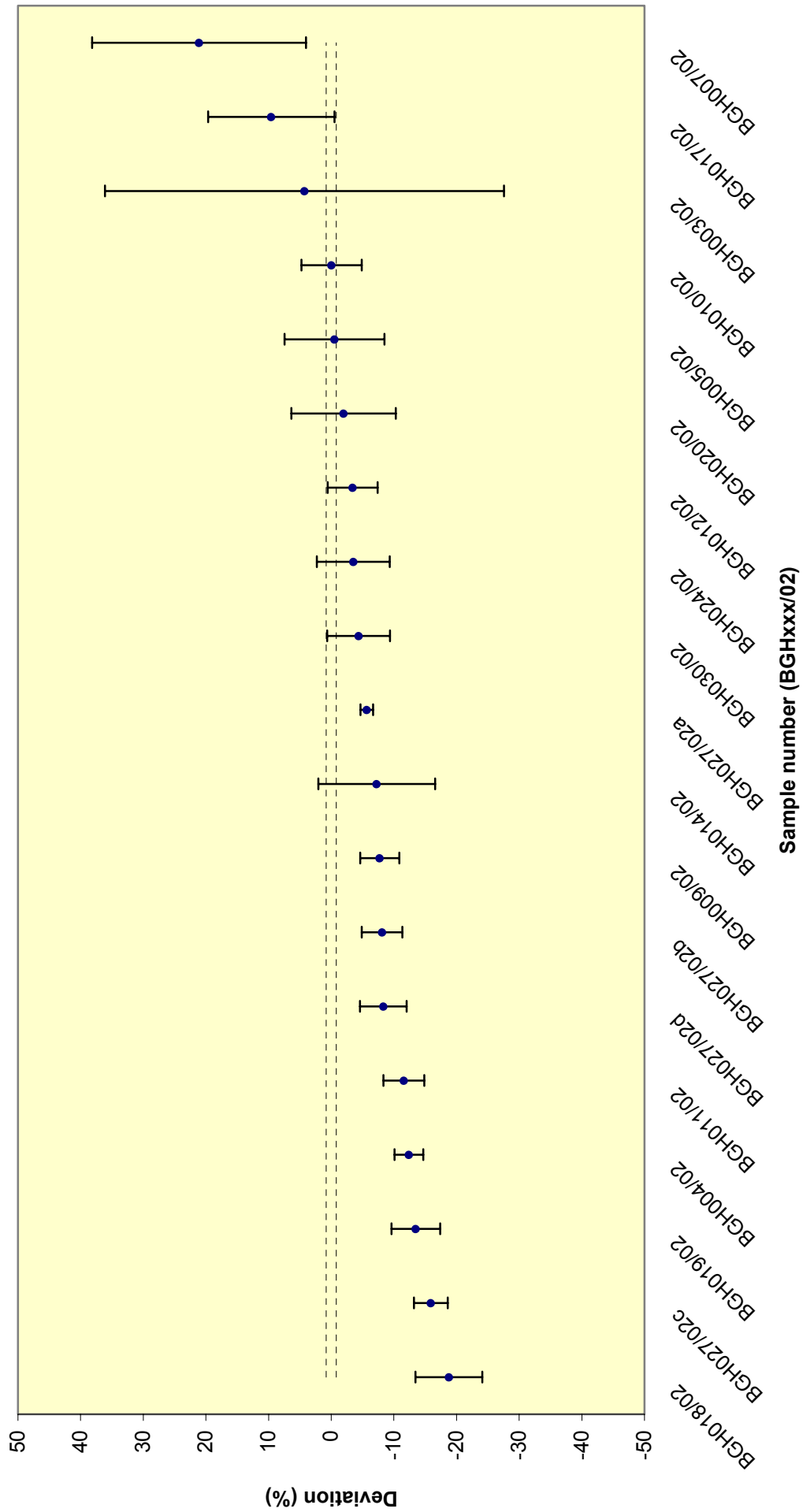


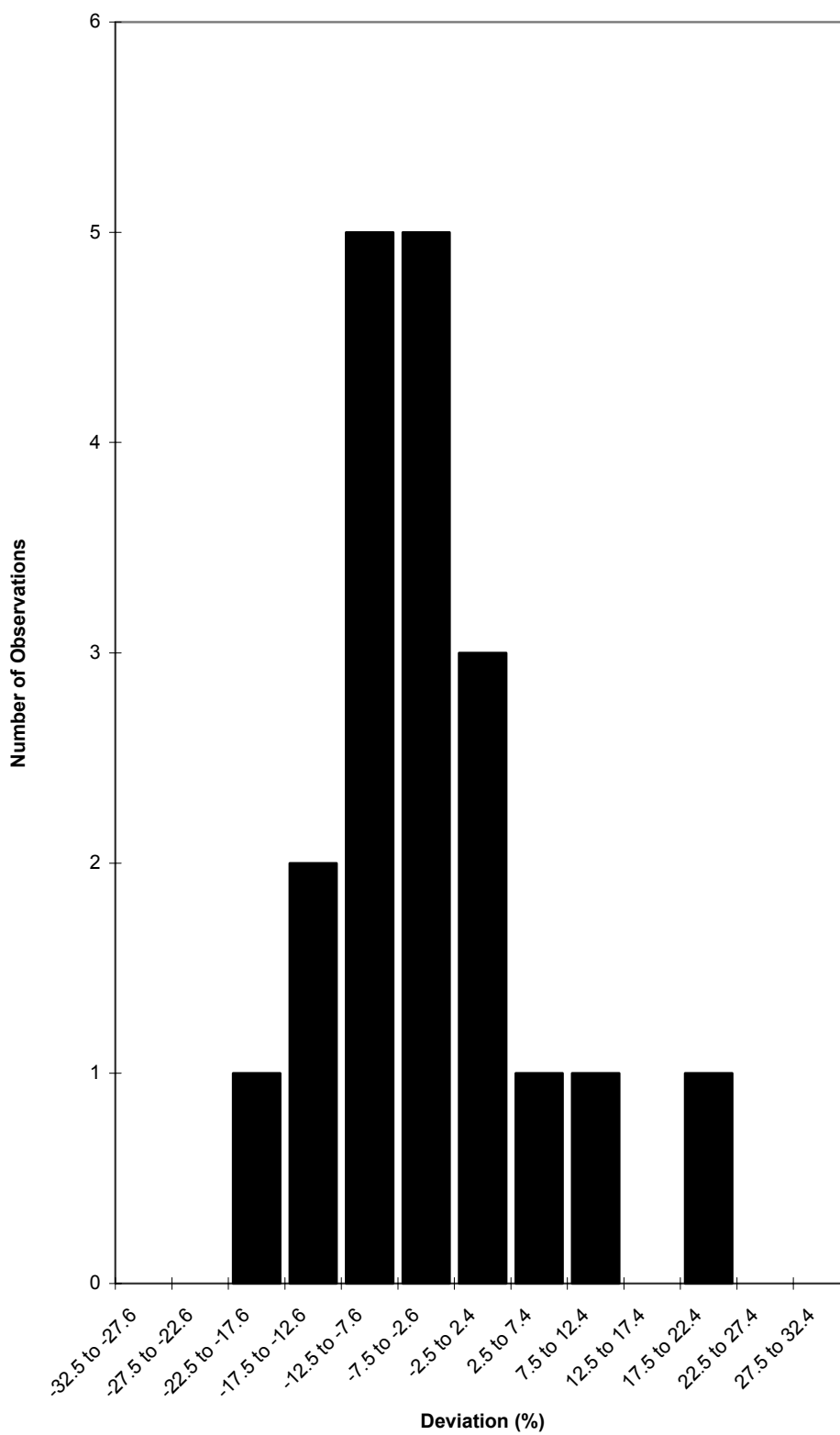
Figure 68 ^{154}Eu high level results

Figure 69 - Reported ^{155}Eu results (high level)

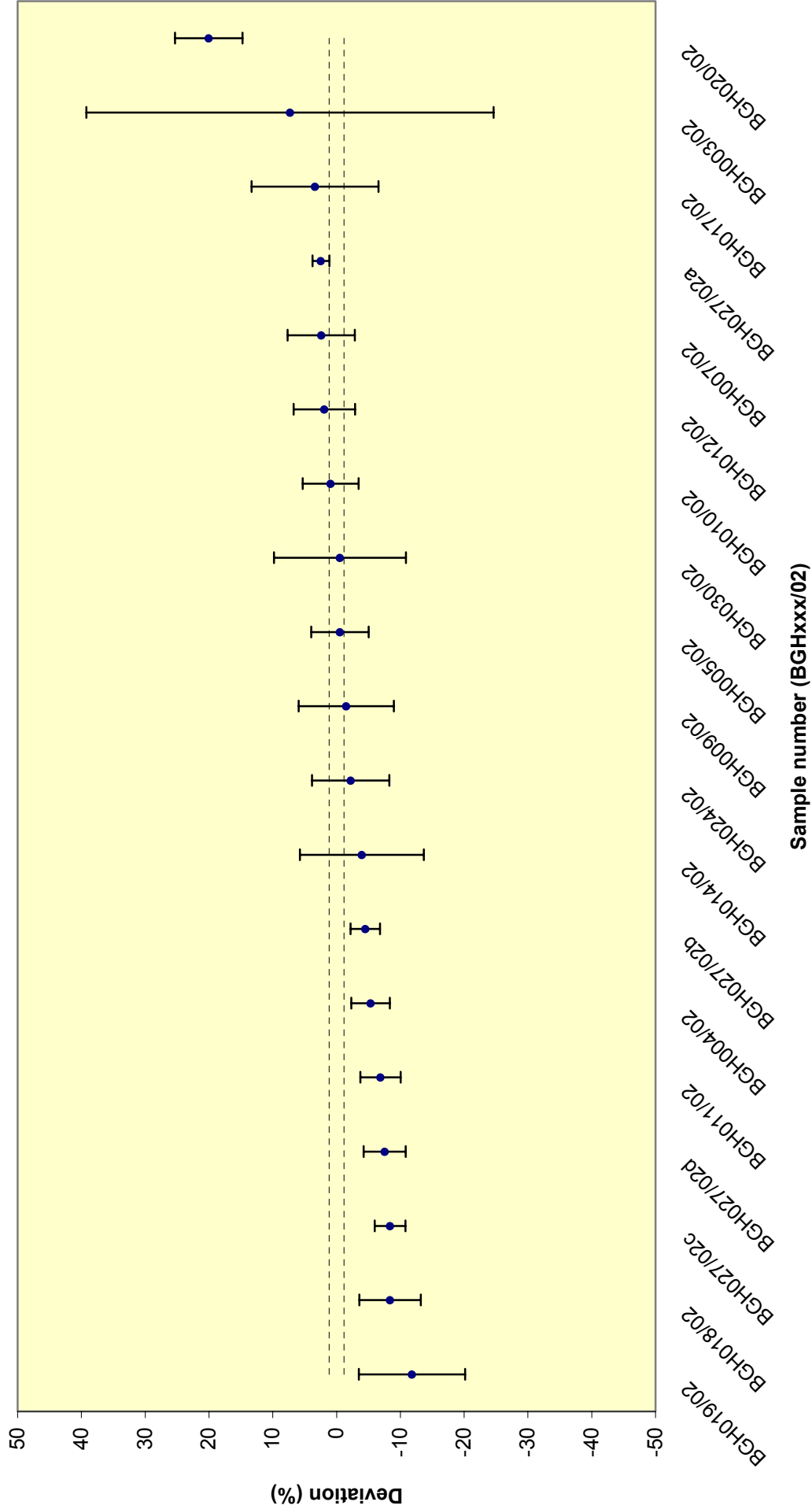
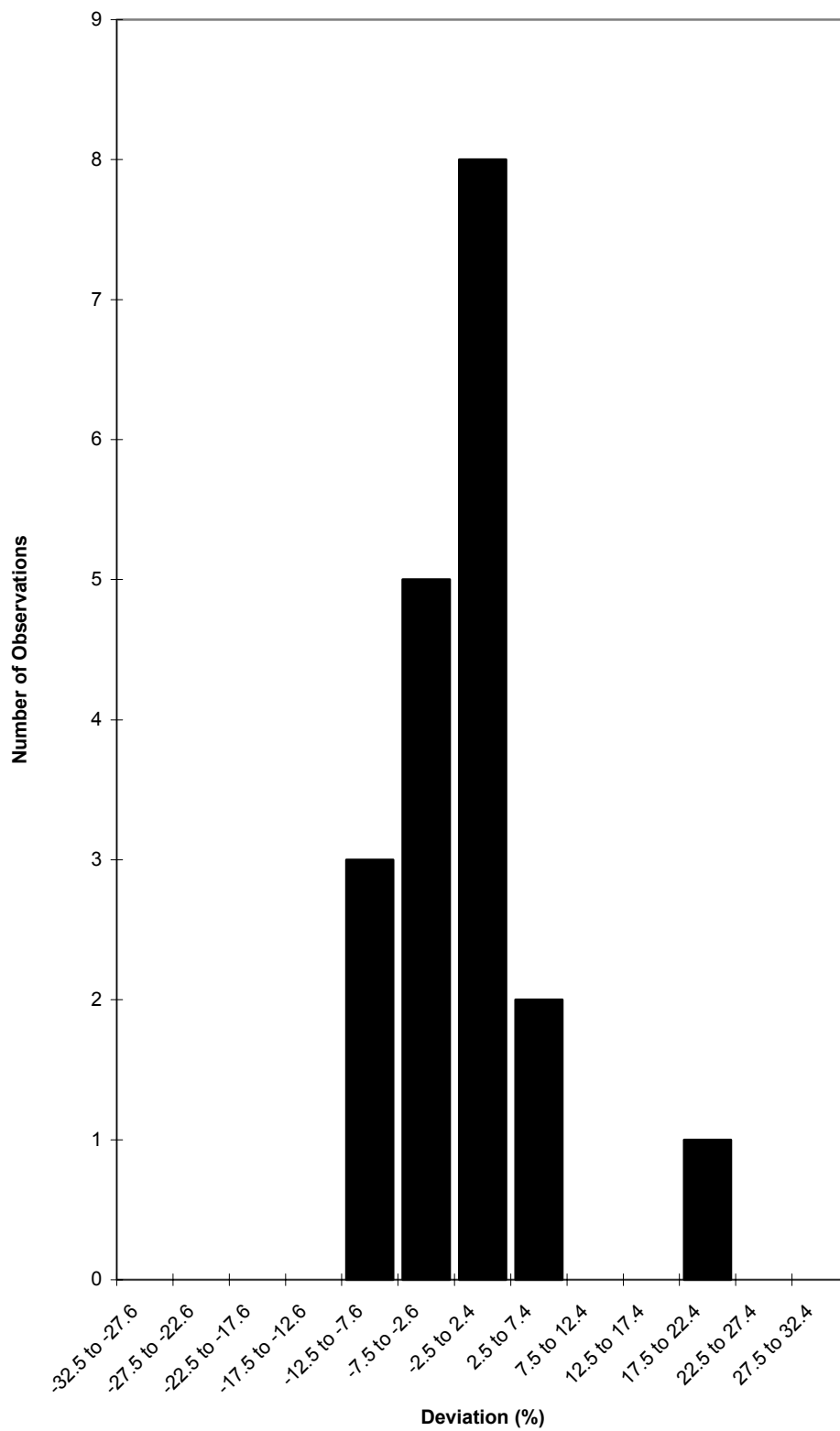


Figure 70 ^{155}Eu high level results

APPENDIX 1

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