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Environmental Radioactivity Intercomparison Exercise, 1996

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ABSTRACT

The results of the sixth in a series of environmental radioactivity intercomparison exercises are reported. In general, results have been achieved which are comparable to those obtained in earlier exercises. Analyses of actinides (in an aqueous matrix) have shown some improvements although measurements of β -emitting and γ -emitting radionuclides (also in aqueous matrices) were only marginally better than in recent years. Measurements of γ -emitters in milk proved more problematic, with a greater proportion of discrepant results being in evidence than for the aqueous sample, which had the same radionuclidic composition. Some laboratories are still quoting uncertainties which are lower than the corresponding NPL value.

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1 INTRODUCTION

NPL has conducted a sixth environmental radioactivity measurement intercomparison, continuing the series of such exercises¹⁻⁵ which began in 1989. The exercise was organised in a manner similar to previous years, using three sample types: (i) α -emitting and pure β -emitting radionuclides in an aqueous matrix (dilute nitric acid), (ii) γ -emitting radionuclides in an aqueous matrix (dilute hydrochloric acid), and (iii) γ -emitters in milk.

This results of this intercomparison are presented and discussed in this report. It should be noted that this report supersedes NPL Report CIRA(EXT)023⁶, which quoted incorrect values for the activity concentrations of ¹⁵⁴Eu and ¹⁵⁵Eu in the γ -emitting samples.

2 ORGANISATION

2.1 PARTICIPANTS

Of the 41 participants in this year's exercise, 35 requested γ -emitters in the aqueous matrix, 18 accepted γ -emitters in milk and 18 took the α/β -emitter mixture. As in previous years, the participants came from four groups: (i) the nuclear industry and government departments in the UK, (ii) UK organisations with a secondary interest in the nuclear industry (e.g. regional analysts, research organisations), (iii) UK contract laboratories with no special interest in the nuclear industry, and (iv) overseas laboratories. The participants are listed in Appendix 1.

2.2 SAMPLES

The three sets of samples prepared were coded as follows:

- (i) α/β -emitters: ABx/96
- (ii) γ -emitters (aqueous): BGx/96
- (iii) γ -emitters (milk): BGMx/96

In each case, 'x' was a numerical identifier specific to each individual participant.

The radionuclides were restricted to those which are emitted/produced at some stage of the nuclear fuel cycle and are present in the environment in varying quantities. The criteria adopted in the selection of the radionuclides were as in previous years, viz.:

- (i) that the half-lives were > 50 days;
- (ii) that no obscure species were selected (i.e. that could reasonably be found in the environment or in 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.

The radionuclidic composition of the α/β -emitter samples was disclosed in order to minimise the analytical effort required, since radiological procedures for the quantification of α -emitters and pure β -emitters are invariably time consuming and thus costly in terms of staff effort and resources. The compositions of the γ -emitter samples (both aqueous and milk matrices) were not disclosed since the analytical technique normally used for such samples enables the user to identify the constituent radionuclides in a straightforward manner. The following candidate list of radionuclides was provided: ^7Be , ^{22}Na , ^{46}Sc , ^{54}Mn , ^{56}Co , ^{57}Co , ^{58}Co , ^{60}Co , ^{65}Zn , ^{85}Sr , ^{88}Y , ^{95}Zr , ^{95}Nb , $^{106}\text{Ru}/^{106}\text{Rh}$, ^{109}Cd , $^{110\text{m}}\text{Ag}$, ^{113}Sn , ^{124}Sb , ^{125}Sb , $^{125\text{m}}\text{Te}$, ^{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 .

The approximate activity concentrations for each radionuclide in each of the three sample types is given in Table 1.

3 CALIBRATION

3.1 ABSOLUTE CALIBRATION

An absolute standard of radioactivity is one measured from count-rate data alone, without reference to any other radioactivity standards or supplementary data. A primary standard is the highest level standard in any measurement system hierarchy; in most cases, primary standards are also absolute standards.

Absolute standards of radioactivity are usually derived using the 4π -proportional counter- γ -coincidence counting technique⁷ for α/γ -emitting, e.c./ γ -emitting and β/γ -emitting radionuclides. Radionuclides which decay by pure α or pure β emission can be determined by variations of this technique.

3.2 SECONDARY STANDARDISATION

Absolute counting techniques are not normally used for routine assays because (i) they are labour intensive and therefore prohibitively expensive, (ii) the uncertainties involved become unacceptably high below a particular activity limit, and (iii) the system limits the activity of such solutions to 50 - 500 kBq g⁻¹. Absolutely standardised solutions are therefore used to calibrate secondary standard instruments.

For γ -emitting radionuclides and some pure β -emitters, the instrument of choice is a 'well-type' ionisation chamber; this responds to γ -radiation and also to bremsstrahlung radiation arising from the more energetic β -emitters. Other γ -ray detectors such as NaI(Tl) crystals and hyperpure Ge crystals may also be used but do not have good long-term stability compared to that exhibited by ionisation chambers.

For pure α -emitters and most β -emitters there is no suitable secondary standard instrument, although liquid scintillation counters may be used.

4 SOURCE PREPARATION

4.1 PURITY

The individual nuclides used for the samples in this exercise were procured from reputable sources and standardised as indicated in Table 2. Details of impurities are given in Table 3. The radionuclide ^{240}Pu , which was present in the ^{239}Pu , is metrologically indistinguishable from the latter (unless mass spectrometry is used). An activity concentration equal to the sum of the activity concentrations of ^{239}Pu and ^{240}Pu was therefore quoted by NPL.

4.2 ACTIVITY CONFIRMATION

The activity concentrations of the starting materials were determined either by measurement in an NPL secondary standard ionisation chamber or from a calibration certificate; in the latter case, activity concentrations were confirmed by liquid scintillation counting.

4.3 PREPARATION

4.3.1 Samples in aqueous matrices

Stock solutions of the individual radionuclides were prepared by gravimetric dilution of the standardised solutions. In each case the overall (gravimetrically-determined) dilution factor was confirmed by counting sources made at each dilution stage involved and then comparing observed count-rates. The γ -emitting radionuclides were measured using a NaI(Tl) crystal and the α -emitters and pure β -emitters were measured by liquid scintillation counting.

The stock solutions were used to prepare the customer samples by diluting approximately 1 - 3 g of the relevant stock solution to about 500 g with a diluent acid containing dissolved carriers.

The ABx/96 samples were diluted with about 1.5 M nitric acid containing Ca, Fe, S, Sr and Y carriers, each at a concentration of around 50 $\mu\text{g/g}$ (Ca and Fe were included in the matrix as metal cations that may well be encountered in a typical sample). There are no suitable carriers for Am, Pu, Tc or U; the aqueous matrix acts a carrier for tritium.

The BGx/96 samples were diluted with about 2.5 M hydrochloric acid containing Ba, Cs, Co, Sb, Te and Eu carriers, each present at around 25 $\mu\text{g/g}$.

4.3.2 Milk samples

This required a different preparation technique. Dried skimmed milk powder (50 g) was reconstituted with deionised water (450 g) in a 500 ml plastic bottle. The milk was then spiked with weighed aliquants of the seven radionuclides (in aqueous matrices). The acidity of the spiked milk was such that it would remain stable to the naked eye for several days if refrigerated.

The milk samples were prepared on a weekly basis as required by the participants. They were refrigerated immediately after preparation, packed in 'cold packs' for transit and delivered within 48 hours of preparation.

5 TREATMENT OF DATA

5 NUMERICAL DATA

In accordance with practice in previous intercomparisons, data reporting forms were prepared and distributed with the samples. The data returned was used in conjunction with NPL data to calculate two main parameters. Firstly, the deviation from the NPL value was calculated as a percentage:

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

The value of the u-statistic⁸ was also calculated:

$$u\text{-statistic} = \frac{|\text{Analyst's result} - \text{NPL value}|}{\sqrt{\text{Analyst's uncertainty}^2 + \text{NPL uncertainty}^2}}$$

This statistic is compared with values in the t-statistic tables⁹ and assessed in accordance with the criteria in Table 4.

5.2 NUCLEAR DECAY DATA

The data used by the participants are discussed later; the data¹⁰⁻¹⁶ used by NPL for this work are given in Table 5. In each case, the γ -ray emission probabilities, P_γ , are only given if they exceed 1%; the uncertainties on these values are quoted at the 1σ level, as are all other uncertainties quoted herein.

5.3 PRESENTATION

The results of u-tests are summarised in Tables 6 to 9.

The participants' results for the radionuclides included in the samples by NPL are tabulated in Tables 10 to 31 and are plotted in Figures 1 to 46. Additional data supplied by the participants is given in Table 32.

5.4 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 β -EMITTERS

6.1 GENERAL COMMENTS

In total, 18 sets of data were returned, although only one laboratory carried out an analysis of all 8 components of the sample. All participants used radiochemical analysis to resolve the constituent radionuclides. These analyses were more complex than those used for the γ -emitters, although the data processing was simpler, the activity concentration of a given radionuclide normally being calculated from:

$$A = \frac{C}{\epsilon.Y.W.D}$$

where A is the activity concentration
 C is the observed count-rate
 ϵ is the detection efficiency
 Y is the chemical yield
 W is the sample weight
 and D is the radioactive decay factor

The detection efficiency ϵ is determined by calibrating the detector with a known standard of the analyte; Y is determined by adding a known amount of a chemical yield tracer and measuring its recovery (for tritium, the bulk matrix acts as a yield tracer).

6.2 ^{238}U

Twelve sets of results were returned for this radionuclide (see Table 10 and Figures 1 - 2). In most cases, ion exchange or extraction chromatography were used as the separation technique followed by electrodeposition onto a stainless steel disc prior to α -counting. Some participants used preconcentration techniques (e.g. precipitation, evaporation or solvent extraction). One laboratory used ICP-MS to measure the sample. Where a yield tracer was used, ^{232}U (from either NPL, AEA Technology Harwell or LPRI) was always adopted. The mean bias was 0.985 ± 0.047 with no results being clearly discrepant but with one result being probably discrepant*. It is disturbing to note that five laboratories are quoting uncertainties which are lower than the corresponding NPL values; this strongly suggests that these laboratories' uncertainty budgets are not comprehensive. It can only be to the advantage of the analyst to quote an overall uncertainty which takes fully into account all random and systematic components; in the one case where the u-statistic suggested a dubious result, the discrepancy could have been removed if the quoted uncertainty was at least as great as the NPL value.

6.3 $^{238}\text{Pu}/(^{239}\text{Pu}+^{240}\text{Pu})$

The results for ^{238}Pu are given in Table 11 and are illustrated in Figures 3 - 4; those for $^{239}\text{Pu}+^{240}\text{Pu}$ are given in Table 12 and in Figures 5 - 6. The same techniques as for ^{238}U were used for source preparation and counting. Two laboratories used ^{236}Pu ** (from AEA Technology) as a yield tracer and ten laboratories used ^{242}Pu (from either NPL or AEA Technology). The biases observed were 0.934 ± 0.037 for ^{238}Pu and 1.018 ± 0.036 for $(^{239}\text{Pu}+^{240}\text{Pu})$. All participants used α -spectrometry to measure the $(^{239}\text{Pu}+^{240}\text{Pu})$ so the activity concentrations quoted for ^{239}Pu would have been the sum of the activity concentrations of these two radionuclides, in all cases. There was one clearly discrepant result, and one further result probably discrepant, for ^{238}Pu ; no discrepant data were reported for $(^{239}\text{Pu}+^{240}\text{Pu})$. This continues the improvement in the quality of data for these radionuclides (in the 1995 exercise nearly 50% of the data was discrepant). Three laboratories quoted ^{238}Pu uncertainties lower than the corresponding NPL value, although all the $(^{239}\text{Pu}+^{240}\text{Pu})$ uncertainties were reasonable.

* For the purposes of this report, data yielding a u-statistic > 3.29 are regarded as discrepant, whereas data yielding a value between 2.58 and 3.29 are regarded as probably discrepant.

** It should be noted that ^{236}Pu decays to ^{232}U so its use as a yield tracer can complicate U analyses.

6.4 ^{241}Am

Eighteen participants returned 25 data sets for this nuclide (see Table 13 and Figures 7 - 10), eleven being α -spectrometric measurements, thirteen being measured by γ -spectrometry and one by ICP-MS. The biases were 1.004 ± 0.159 (α -spectrometry only), 0.994 ± 0.086 for (γ -spectrometry only) and 1.014 ± 0.140 (all data). The one ICP-MS result was 36.98% higher than the NPL value but it is difficult to make judgements on the technique on the basis of just one result.

The percentage of discrepant γ -spectrometric data is much the same as in recent years (< 10%, albeit with one further doubtful result) but there has been an improvement in the α -spectrometric data (40 - 45% were discrepant in 1994-5 compared with 18% this year). All quoted uncertainties exceed the NPL values.

 ^3H

See Table 14 and Figures 11 - 12. In all but one case (in which extraction chromatography was used), the tritium was isolated by distillation. All determinations were made by liquid scintillation counting. Two participants made corrections for isotopic fractionation during distillation. This arises because of the differing physicochemical properties (e.g. boiling points) of tritiated water and water (H_2O). Tritiated water standards were used, most of which were traceable to national standards. A variety of nuclear data sources were adopted but in most cases they were from recognised sources. The bias was 1.008 ± 0.074 . One laboratory quoted an unrealistically low uncertainty.

The percentage of clearly discrepant results has fallen from 41% in 1995 to 28% this year; however, the 1994 exercise, in which no discrepant data were reported for this radionuclide, illustrates that far better performance is achievable and it is cause for concern that this was not forthcoming in the current exercise. Three of the five participants who reported discrepant results had used a half-life of 12.43 years (compared with an NPL-recommended value of 4507.2 ± 3.7 days¹⁰ (equivalent to 12.34 years)) although this factor alone would not make a significant difference. One of the other two laboratories was the only one to have used extraction chromatography to separate the tritium, which may be significant.

 ^{35}S

Only five laboratories attempted an analysis of this radionuclide; the results are given in Table 15 and in Figures 13 - 14. In each case, the sample was chemically pretreated (e.g. using Benedicts' solution*) and ultimately converted to barium sulphate which was then determined by suspension (scintillation) counting. Three laboratories used ion exchange chromatography to separate the cations present prior to precipitation of the sulphate. A bias of 0.900 ± 0.220 was observed with two of the five reported results being discrepant (approximately the same proportion as in the 1990 exercise); however, more data is needed to give an overall picture of measurement capability for this radionuclide. Most analysts used traceable standards and recognised nuclear data sources.

* An aqueous solution of sodium carbonate, copper sulphate and sodium citrate.

6.7

Nine laboratories reported data for this radionuclide (see Table 16 and Figures 15 - 16). Several techniques (e.g. ion exchange, extraction chromatography) were used to separate Sr from Y and in all cases the basic principle involved was to allow Y to ingrow into purified Sr and to then separate and count the Y. Liquid scintillation counting, Čerenkov counting and proportional counting were used as the assay technique. Some laboratories used ^{85}Sr as a yield tracer. The bias of 1.018 ± 0.239 was similar to those from recent exercises. About 22% of the data was discrepant (compared with 25-40% in the last four exercises); this is a modest improvement and one would perhaps expect still better performance in future.

6.8

Only three data sets (see Table 17 and Figures 17 - 18) were returned for this radionuclide and again this precludes general conclusions and makes comparisons with recent exercises difficult. Each laboratory used a different separation technique (e.g. ion exchange, precipitation and solvent extraction); one used Rh as a carrier. Two laboratories used gas proportional counters and one used liquid scintillation counting. The bias was low at 0.962 ± 0.028 . One of the results was dubious, yielding a u-statistic of 2.63; it may be significant that the corresponding uncertainty, although higher than NPL's, is low compared with the other participants' uncertainties.

7 RESULTS FOR γ -EMITTERS

7. GENERAL COMMENTS

As in previous years, most of the data reported was for the γ -emitters, with 35 data sets being returned for the aqueous sample and 18 for the milk sample; three participants reported two results for their aqueous samples. All the participants used semiconductor detectors and all but one used commercially supplied data handling software. Again, nearly all the participants used efficiency calibration standards of the mixed radionuclide type and in three cases such standards were used in conjunction with single nuclide standards. The use of nuclear decay data recommended by NPL was again very much in evidence, with 13 participants using such data either alone or in conjunction with data from elsewhere. A further 18 analysts used data from their own software libraries, eight of them having updated those libraries.

7.2 AQUEOUS SAMPLES

7.2.

This is used as a calibration radionuclide. The results (given in Table 18 and illustrated in Figures 19 - 20) show a bias of 1.034 ± 0.173 ; 24% of the results are clearly discrepant and 3% probably so. Again it is noticeable that six laboratories quoted unrealistically low uncertainties, in three cases leading to data which is clearly discrepant.

7.2.2

This is an activation product and calibration radionuclide (see Table 19 and Figures 21 - 22). The bias of 1.023 ± 0.107 is higher than in previous years, even though four laboratories made corrections for cascade summing. However, 11% of the results are clearly discrepant (and a further 5% probably so). Although this is an improvement on recent exercises (18% in 1994, 21% in 1995) it is still worrying

that more than 10% of results are in error for a calibration radionuclide. Here, five laboratories quoted uncertainties lower than NPL's; however, this did not make any results discrepant.

^{125}Sb

This radionuclide, a fission product, is prevalent in waste effluent streams (see Table 20 and Figures 23 - 24). The data show a bias of 1.059 ± 0.140 . Two results have uncertainties lower than NPL's but this did not create discrepant results. Of the results, 13% are clearly discrepant. Two laboratories made cascade summing corrections.

^{134}Cs

This radionuclide occurs widely in nuclear waste and throughout various ecosystems. Measurements are complicated by cascade summing; eight participants made corrections for this (see Table 21 and Figures 25 - 26). The bias is 0.961 ± 0.148 . Discrepant results run at 18% (a further 3% probably so). This is in line with recent exercises (15-16% in 1994 and 1995). Five laboratories reported uncertainties lower than NPL's; three of these values led to results being discrepant.

^{137}Cs

This is a fission product and is also used as a calibration nuclide. It occurs widely in the environment, mainly as a result of nuclear weapons testing but with a contribution from the Černobyl accident fallout. The results (Table 22, Figures 27 - 28) show a bias is 0.998 ± 0.067 . Around 11% of the results are clearly discrepant (3% probably so), which is a modest improvement on recent exercises (12-21% in 1993-5). Four uncertainties are lower than NPL's, in one case leading to a discrepant result.

^{154}Eu

This is formed by neutron activation of stable europium. It emits several γ -rays, some of which are emitted in cascade. There are sufficient γ -rays with no interferences to permit identification to be made. The results (Table 23, Figures 29 - 30) exhibit a bias of 1.003 ± 0.121 , and 11% of the results are clearly discrepant (11% probably so); this is an improvement on the last three exercises, in which discrepant results ran at > 20%. However, three participants have quoted uncertainties lower than NPL's and in two cases this has led to a discrepant result. Cascade summing corrections were made by five laboratories.

^{155}Eu

Another fission product but with a low fission yield. It's determination is complicated by the fact that it emits low-energy γ -rays in a region of the calibration curve where the rate of change of detector efficiency with energy is large. The bias is 1.017 ± 0.189 (see Table 24, Figures 31 - 32). Four uncertainties are lower than NPL's, two yielding values of $u > 2.58$; 18% of the results are clearly discrepant. The fairly large spread of results points to the difficulty of measuring this radionuclide, due in part to the low energy of its γ -ray emissions.

7.3 MILK SAMPLES

7.3.1 ^{57}Co

The results for this radionuclide are given in Table 25 and illustrated in Figures 33 - 34. The bias is 1.074 ± 0.230 and eight of the results (or 47%) are discrepant; curiously, only two of these eight laboratories also obtained a discrepant result for the aqueous sample. Four uncertainties are lower than NPL's, three leading to discrepant results.

7.3.2 ^{60}Co

Here, the data (Table 26, Figures 35 - 36) shows a lower bias than for the aqueous samples (1.004 ± 0.101). Again, a greater proportion of results (22%, or a total of four laboratories) are discrepant than was the case for the aqueous sample; none of these four laboratories also obtained discrepant results for their aqueous sample. A further 11% of the results are probably discrepant.

7.3.3 ^{125}Sb

The bias and spread (1.071 ± 0.141) on the results (Table 27, Figures 37 - 38) are comparable to the aqueous sample. Some 22% of the results are clearly discrepant (in this case, two of the four discrepant laboratories also obtained discrepant results for the aqueous sample).

7.3.4 ^{134}Cs

Again, the results (see Table 28 and Figures 39 - 40) exhibit a bias comparable to the aqueous samples at 0.957 ± 0.103 . Of the data, 28% are clearly discrepant, again a greater proportion than for the aqueous sample (three of the five discrepant laboratories obtained discrepant results for the aqueous sample). Two of these discrepant results correspond to participant uncertainties lower than NPL's.

7.3.5 ^{137}Cs

Here the bias and spread (1.040 ± 0.089) are markedly different from the acid samples (the results are given in Table 29 and Figures 41 - 42). Around 11% of the data can be regarded as clearly discrepant (and a further 17% are probably so), again higher than for the aqueous sample; however, these same laboratories obtained satisfactory results for the aqueous sample. Two uncertainties were lower than NPL's, one yielding a (probably) discrepant result.

7.3.6 ^{154}Eu

Here, 17% of the data are clearly discrepant (and a further 17% probably so), yet again higher than for the aqueous sample. The results are given in Table 30 and shown in Figures 43 - 44. One of the participants' uncertainties is lower than NPL's, once again leading to discrepancy. Again, two of the three clearly discrepant results correspond to discrepant aqueous sample results. The bias is 1.032 ± 0.239 .

7.3.7 ^{155}Eu

Here, 44% of the results (see Table 31 and Figures 45 - 46) are clearly discrepant. Three of the laboratories reported low uncertainties, two leading to clear discrepancies. The bias is 1.020 ± 0.257 .

8 DISCUSSION

8 AQUEOUS SAMPLES

α -emitters

In terms of the numbers of discrepant results, there has been an improvement on recent exercises for measurements of ^{238}Pu , ($^{239}\text{Pu}+^{240}\text{Pu}$) and ^{241}Am (α -spectrometry). However, there are still five laboratories who are quoting uncertainties (for ^{238}U and/or ^{238}Pu) which are less than the corresponding NPL values, clearly indicative of incomplete uncertainty budgets. One participant used ICP-MS to measure ^{238}U and ^{241}Am . The result for the former was satisfactory but the result for the latter was clearly discrepant; however, this is unsurprising since the levels of ^{241}Am present are at or below the perceived limits of detection for ICP-MS assay. Much more data is needed to evaluate fully this technique for actinide analysis at these levels. Measurements of ^{241}Am by γ -spectrometry agreed with α -spectrometric data in 80% of cases where both techniques were used. It was encouraging that, in virtually all cases, recognised standards and nuclear data sources were adopted by the participants.

β -emitters

The overall shortage of data for ^{35}S and ^{99}Tc makes it difficult to draw conclusions for these radionuclides. Overall performance for tritium was better than in the previous exercise but considerably worse than in the 1994 exercise and the reasons for this are not clear; the results for ^{90}Sr , although marginally better than in recent exercises, are still unsatisfactory with > 20% of the data being discrepant. It may be significant that the discrepant results were obtained from Čerenkov counting of ^{90}Y , although others did use this technique successfully; Čerenkov counting is sensitive to the refractive index of the sample matrix, so proper control of this parameter must be achieved.

γ -emitters

The results for the aqueous sample revealed a level of metrological performance comparable to, and in some cases marginally better than, the results of previous exercises. The numbers of clearly discrepant results (i.e. $u > 3.29$) were in the range 11-24%, but if one also includes the results which are probably discrepant (i.e. for which $2.58 < u < 3.29$), the range is 13-31%. It is of some concern that calibration radionuclides such as ^{57}Co , ^{60}Co and ^{137}Cs are still causing significant problems; if one looks at the proportion of results which unambiguously agree with the corresponding NPL value, the figures are only 57%, 55% and 66% respectively. It is noticeable, in some cases, that when a results giving a large bias is reported for ^{57}Co , a bias of a similar magnitude (but of opposite sign) is apparent from the reported result for ^{154}Eu .

There are still a significant number of quoted uncertainties (around 13% of the total for the aqueous samples) which are smaller than the value quoted by NPL; this percentage corresponds to a total of 33 results, 13 of which are discrepant. These uncertainties were not randomly distributed across all participants but were quoted by a group of five laboratories.

Although the results were clearly affected by cascade summing, around 30% of the participants made corrections (e.g. for ^{60}Co , ^{125}Sb , ^{134}Cs and ^{154}Eu).

8.2 MILK SAMPLES

8.2. γ -emitters

The numbers of clearly discrepant results were in the range 11-28% (except for ^{57}Co and ^{155}Eu where the figures were 47% and 44% respectively), but these percentages rise when one considers data yielding $u > 2.58$, particularly for ^{60}Co and ^{154}Eu , where 33-34% of reported data are in doubt. Of the calibration radionuclides (^{57}Co , ^{60}Co and ^{137}Cs), the proportions of unambiguously correct data are 29%, 50% and 67% respectively. Around 10% of the uncertainties were low, all stemming from a group of four laboratories (three being from the aforementioned group of five). The uncertainties quoted for the milk samples were, by and large, comparable to those quoted for the aqueous samples.

All but one of the participants used calibrations based on mixed radionuclide type standards. If hydrochloric acid (4M) is used as the diluent for such standard solutions, the difference in density between the matrices of the standard and the analyte is very small ($< 0.5\%$; both values are about 1.06 g/cm^3) so the use of aqueous standards provides a good approximation to a 'spiked milk' calibration. However, in using such a standard the analyst has to make assumptions which cannot easily be quantified, and ideally a milk SRM should be used.

8.3 GENERAL COMMENTS

8.3.1 Nuclear decay data

The nuclear decay data used by the analysts come from a variety of data libraries, either as supplied by the manufacturer of the particular equipment used, or directly from an internationally recognised nuclear data source such as IAEA TecDoc 619¹¹. It is of note that a majority of analysts are showing increased concern over the quality of the nuclear decay data that they are using. This trend is reflected in the practice of extracting a working data library from the manufacturer's software and updating these data with the most recent recommended values from, for example, IAEA TecDoc 619 or NPL RSA(EXT)53¹².

NPL fully supports the continuation of this practice. However, it is of concern that some users are still using what are considered old, and possibly unreliable, data. It is the view of the nuclear data community within the UK, as represented by the UKNSF, that the use of such data should strongly be discouraged. If there is any doubt as to the reliability of nuclear decay data, an expert body such as NPL should be contacted with regard to advice on the best data sources currently available.

8.3.2 Standards

The usage of calibration standards of the mixed radionuclide type for the measurement of γ -emitting radionuclides is now almost universal among participants in these exercises, and this is to be welcomed, provided that the analyte is of comparable density to the standard. Analysis of α -emitting and β -emitting nuclides is in most cases underpinned by standards and chemical yield tracers drawn mainly from three principal suppliers (NPL, Amersham International plc and AEA Technology plc).

9 CONCLUSIONS

The exercise produced results which demonstrated improvement in metrological performance in some areas (such as measurements of actinides) but a 'levelling off' of performance in others (such as β -emitter analyses). There are modest improvements in γ -emitter analyses but it is worrying that such

a high proportion of results for the radionuclides commonly used in calibration standards (such as ^{60}Co) are not unambiguously correct, and that more than a quarter of the total number of results quoted are discrepant or probably so.

A few laboratories are quoting uncertainties lower than those quoted by NPL, clear evidence that their uncertainty budgets are incomplete. It should be noted that this may also be the case where the participant's uncertainty exceeds the NPL value. This has highlighted a potential area for training.

The measurements of the milk samples were of a similar quality to those of the aqueous samples, albeit with a greater proportion of discrepant results. This may be due to the general usage of aqueous calibration standards.

One can therefore conclude that:

- (i) there is still scope for improvement in measurement performance, even for radionuclides in aqueous matrices;
- (ii) specific areas for such improvement include the compilation of comprehensive uncertainty budgets;
- (iii) there is an ongoing need to assess measurement capabilities for non-aqueous matrices.

The United Kingdom Accreditation Service, UKAS, is continuing to accredit laboratories (under NAMAS) for radioactivity measurements and see these exercises as an important aspect of laboratory Quality Assurance.

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Table 1 - Approximate activity concentrations

Sample	Nuclide	Emission	Level/ (Bq/kg)
ABx/96	²³⁸ U	α	~1-10
	²³⁸ Pu	α	~3-18
	²³⁹ Pu	α	~3-15
	²⁴⁰ Pu	α	~0.1-0.5
	²⁴¹ Am	α/γ	~5-24
	³ H	β	~350-1800
	³⁵ S	β	~20-90
	⁹⁰ Sr	β	~70-350
BGx/96	⁹⁹ Tc	β	~50-230
	⁵⁷ Co	e.c.*/ γ	~10-80
	⁶⁰ Co	β/γ	~10-80
	¹²⁵ Sb	β/γ	~10-80
	¹³⁴ Cs	β/γ	~10-80
	¹³⁷ Cs	$\beta, \beta/\gamma$	~10-80
	¹⁵⁴ Eu	β/γ	~10-80
	¹⁵⁵ Eu	β/γ	~10-80
BGMx/96	⁵⁷ Co	e.c.*/ γ	~10-80
	⁶⁰ Co	β/γ	~10-80
	¹²⁵ Sb	β/γ	~10-80
	¹³⁴ Cs	β/γ	~10-80
	¹³⁷ Cs	$\beta, \beta/\gamma$	~10-80
	¹⁵⁴ Eu	β/γ	~10-80
	¹⁵⁵ Eu	β/γ	~10-80

* e.c. denotes electron capture

Table 2 - Radionuclide provenance

Radionuclide	Origin	Calibrating laboratory	Traceability
²³⁸ U	ORNL, USA	NPL	French Primary Standard/LPRI
²³⁸ Pu	CEA, France	CEA/NPL	UK Primary Standard/NPL
(²³⁹ Pu+ ²⁴⁰ Pu)	CEA, France	CEA/NPL	UK Primary Standard/NPL
²⁴¹ Am	AI, UK	NPL	UK Primary Standard/NPL
³ H	AI, UK	AI	US Primary Standard/NIST
³⁵ S	AI, UK	AI	UK Primary Standard/NPL
⁹⁰ Sr	AI, UK	NPL	UK Primary Standard/NPL
⁹⁹ Tc	AI, UK	AI	UK Primary Standard/NPL
⁵⁷ Co	AI, UK	NPL	UK Primary Standard/NPL
⁶⁰ Co	AI, UK	NPL	UK Primary Standard/NPL
¹²⁵ Sb	AI, UK	NPL	UK Primary Standard/NPL
¹³⁴ Cs	AI, UK	NPL	UK Primary Standard/NPL
¹³⁷ Cs	AI, UK	NPL	UK Primary Standard/NPL
¹⁵⁴ Eu	NPL, UK	NPL	UK Primary Standard/NPL
¹⁵⁵ Eu	IIR, Czech Republic	NPL	UK Primary Standard/NPL

AI: Amersham International plc, UK; CEA: Commissariat à l'Énergie Atomique, France; IIR: Inspektorát pro Ionizující Záření, Czech Republic; LPRI: Laboratoire Primaire des Rayonnements Ionisants, France; NIST: National Institute of Standards and Technology, USA; ORNL: Oak Ridge National Laboratory, USA

Table 3 - Radionuclide impurities

Radionuclide	Impurity	Level (as % of activity concentration of principal radionuclide at reference time)
^{238}Pu	unspecified α -emitters	< 0.15
^{239}Pu	^{240}Pu ^{241}Pu ^{242}Pu ^{241}Am	3.28 6.70 <0.01 0.76
^{154}Eu	^{152}Eu ^{155}Eu	0.51 0.76
^{155}Eu	^{152}Eu ^{154}Eu	0.87 1.2

Table 4 - 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 5 - Nuclear decay data

Nuclide	Half life (days)	E_γ (keV)	P_γ (%)	Reference
^3H	4507.2 ± 3.7			[9]
^{35}S	87.5 ± 0.4			[11]
^{57}Co	271.79 ± 0.09	14.4	9.16 ± 0.15	[11]
		122.1	85.60 ± 0.17	[11]
		136.5	10.68 ± 0.08	[11]
^{60}Co	1925.5 ± 0.5	1173.2	99.857 ± 0.022	[11]
		1332.5	99.983 ± 0.006	[11]
^{90}Sr	10516 ± 21			[12]
^{99}Tc	$(7.718 \pm 0.040) \times 10^6$			[10]
^{125}Sb	1007.7 ± 0.6	176.3	6.85 ± 0.07	[11]
		380.5	1.518 ± 0.016	[11]
		427.9	29.7 ± 0.3	[11]
		463.4	10.48 ± 0.11	[11]
		600.6	17.73 ± 0.18	[11]
		606.7	5.00 ± 0.05	[11]
		636.0	11.21 ± 0.12	[11]
^{134}Cs	754.28 ± 0.22	475.4	1.49 ± 0.02	[11]
		563.2	8.36 ± 0.03	[11]
		569.3	15.39 ± 0.06	[11]
		604.7	97.63 ± 0.06	[11]
		795.9	85.4 ± 0.3	[11]
		801.9	8.69 ± 0.03	[11]
		1168.0	1.792 ± 0.07	[11]
		1365.2	3.016 ± 0.011	[11]

Table 5 - Nuclear decay data (continued)

Nuclide	Half life (days)	E_γ (keV)	P_γ (%)	Reference
^{137}Cs	11020 ± 60	661.7	85.1 ± 0.2	[11]
^{154}Eu	3136.8 ± 2.9	123.1	41.2 ± 0.5	[11]
		247.9	6.95 ± 0.09	[11]
		591.8	4.99 ± 0.06	[11]
		692.4	1.80 ± 0.03	[11]
		723.3	20.2 ± 0.2	[11]
		756.8	4.58 ± 0.06	[11]
		873.2	12.24 ± 0.15	[11]
		996.3	10.48 ± 0.13	[11]
		1004.7	18.2 ± 0.2	[11]
		1274.4	35.0 ± 0.4	[11]
^{155}Eu	1770 ± 50	60.0	1.14 ± 0.12	[10]/ [13]
		86.5	34.0 ± 2.4	[13]
		105.3	20.6 ± 1.4	[13]
^{238}U	$(1.632 \pm 0.002) \times 10^{12}$			[14]
^{238}Pu	32030 ± 110			[15]
^{239}Pu	$(8.807 \pm 0.015) \times 10^6$			[10]
^{240}Pu	$(2.397136 \pm 2557) \times 10^6$			[15]
^{241}Am	$(1.5785 \pm 0.0024) \times 10^5$	59.5	36.0 ± 0.4	[11]

Table 6 - Results of u-tests for α -emitters

Nuclide	Limits	Number of results
^{238}U	< 1.64	10
	1.64-1.96	1
	1.96-2.58	0
	2.58-3.29	1
	>3.29	0
^{238}Pu	<1.64	7
	1.64-1.96	2
	1.96-2.58	4
	2.58-3.29	1
	>3.29	1
$(^{239}\text{Pu}+^{240}\text{Pu})$	<1.64	14
	1.64-1.96	1
	1.96-2.58	0
	2.58-3.29	0
	>3.29	0
^{241}Am	<1.64	17
	1.64-1.96	2
	1.96-2.58	1
	2.58-3.29	1
	>3.29	4

Table Results of u-tests for β -emitters

Nuclide	Limits	Number of results
^3H	<1.64	10
	1.64-1.96	1
	1.96-2.58	2
	2.58-3.29	0
	>3.29	5
^{35}S	<1.64	2
	1.64-1.96	1
	1.96-2.58	0
	2.58-3.29	0
	>3.29	2
^{90}Sr	<1.64	7
	1.64-1.96	0
	1.96-2.58	0
	2.58-3.29	0
	>3.29	2
^{99}Tc	<1.64	2
	1.64-1.96	0
	1.96-2.58	0
	2.58-3.29	1
	>3.29	0

Table 8 - Results of u-tests for γ -emitters (aqueous)

Nuclide	Limits	Number of results
⁵⁷ Co	<1.64	21
	1.64-1.96	0
	1.96-2.58	3
	2.58-3.29	1
	>3.29	9
⁶⁰ Co	<1.64	21
	1.64-1.96	8
	1.96-2.58	1
	2.58-3.29	2
	>3.29	4
¹²⁵ Sb	<1.64	19
	1.64-1.96	4
	1.96-2.58	8
	2.58-3.29	0
	>3.29	5
¹³⁴ Cs	<1.64	25
	1.64-1.96	1
	1.96-2.58	2
	2.58-3.29	1
	>3.29	7
¹³⁷ Cs	<1.64	25
	1.64-1.96	0
	1.96-2.58	6
	2.58-3.29	1
	>3.29	4

Table 8 - Results of u-tests for γ -emitters (aqueous) (continued)

Nuclide	Limits	Number of results
^{154}Eu	<1.64	26
	1.64-1.96	1
	1.96-2.58	1
	2.58-3.29	4
	>3.29	4
^{155}Eu	<1.64	18
	1.64-1.96	2
	1.96-2.58	5
	2.58-3.29	4
	>3.29	7

Table 9 - Results of u-tests for γ -emitters (milk)

Nuclide	Limits	Number of results
^{57}Co	<1.64	5
	1.64-1.96	1
	1.96-2.58	3
	2.58-3.29	0
	>3.29	8
^{60}Co	<1.64	9
	1.64-1.96	2
	1.96-2.58	1
	2.58-3.29	2
	>3.29	4

Table 9 - Results of u-tests for γ -emitters (milk) (continued)

Nuclide	Limits	Number of results
^{125}Sb	<1.64	12
	1.64-1.96	0
	1.96-2.58	2
	2.58-3.29	0
	>3.29	4
^{134}Cs	<1.64	10
	1.64-1.96	1
	1.95-2.58	0
	2.58-3.29	2
	>3.29	5
^{137}Cs	<1.64	12
	1.64-1.96	1
	1.95-2.58	0
	2.58-3.29	3
	>3.29	2
^{154}Eu	<1.64	9
	1.64-1.96	0
	1.96-2.58	3
	2.58-3.29	3
	>3.29	3
^{155}Eu	<1.64	5
	1.64-1.96	0
	1.96-2.58	2
	2.58-3.29	3
	>3.29	8

Table 10 - Results for ^{238}U

Sample	NPL Data		Analyst Data		Deviation (%)	u-test statistic
	^{238}U Bq/kg	$\pm$ Bq/kg	^{238}U Bq/kg	$\pm$ Bq/kg		
AB002/96	3.94	0.09	3.94	0.06	0	0
AB006/96	3.98	0.10	3.81	0.13	-4.37	1.10
AB008/96	3.86	0.09	3.81	0.05	-1.30	0.49
AB009/96	5.70	0.13	5.58	0.10	-2.13	0.76
AB010/96	5.77	0.14	6.11	0.44	5.84	0.74
AB011/96	5.86	0.14	5.51	0.43	-5.96	0.78
AB017/96	3.79	0.09	3.71	0.06	-2.04	0.73
AB018/96	3.99	0.09	4.34	0.16	8.85	1.91
AB019/96	4.00	0.09	3.92	0.17	-2.00	0.42
AB025/96	5.83	0.14	5.5	0.3	-5.71	1.02
AB027/96	5.79	0.13	5.7	0.4	-1.55	0.22
AB028/96	5.55	0.13	5.145	0.088	-7.24	2.62

Table 11 - Results for ^{238}Pu

Sample	NPL Data		Analyst Data		Deviation (%)	u-test statistic
	^{238}Pu Bq/kg	$\pm$ Bq/kg	^{238}Pu Bq/kg	$\pm$ Bq/kg		
AB002/96	11.68	0.23	11.2	0.13	-4.11	1.88
AB003/96	11.87	0.23	10.5	0.7	-11.54	1.87
AB005/96	11.81	0.23	10.47	0.46	-11.38	2.63
AB006/96	11.96	0.22	11.92	0.47	-0.34	0.08
AB007/96	11.85	0.23	10.88	0.66	-8.19	1.39
AB008/96	11.74	0.23	10.7	0.20	-8.87	3.47
AB009/96	7.77	0.16	7.47	0.33	-3.90	0.84
AB011/96	7.90	0.16	6.93	0.63	-12.22	1.49
AB017/96	11.85	0.23	10.9	0.3	-8.02	2.52
AB018/96	11.86	0.23	11.19	0.23	-5.62	1.98
AB019/96	12.06	0.23	11.37	0.26	-5.72	1.99
AB022/96	11.66	0.23	10.8	0.8	-7.38	1.04
AB025/96	7.98	0.16	7.4	0.2	-7.07	2.22
AB027/96	7.64	0.16	7.38	0.61	-3.38	0.42
AB028/96	7.40	0.15	7.36	0.11	-0.55	0.23

Table 12 - Results for (²³⁹Pu+²⁴⁰Pu)

Sample	NPL Data		Analyst Data		Deviation (%)	u-test statistic
	(²³⁹ Pu+ ²⁴⁰ Pu) Bq/kg	± Bq/kg	(²³⁹ Pu+ ²⁴⁰ Pu) Bq/kg	± Bq/kg		
AB002/96	5.50	0.05	5.55	0.07	0.91	0.59
AB003/96	5.38	0.05	5.7	0.5	5.95	0.64
AB005/96	5.32	0.05	5.13	0.25	-3.57	0.75
AB006/96	5.48	0.05	5.97	0.28	8.94	1.72
AB007/96	5.26	0.05	5.61	0.36	6.65	0.96
AB008/96	5.34	0.05	5.27	0.06	-1.31	0.90
AB009/96	7.96	0.06	7.87	0.40	-1.13	0.23
AB011/96	8.18	0.07	8.67	0.78	5.99	0.63
AB017/96	5.32	0.05	5.4	0.2	1.50	0.39
AB018/96	5.44	0.05	5.44	0.13	0	0
AB019/96	5.51	0.05	5.55	0.14	0.73	0.27
AB022/96	5.31	0.05	5.18	0.49	-2.45	0.27
AB025/96	8.03	0.06	8.1	0.2	0.87	0.34
AB027/96	8.09	0.06	8.21	0.67	1.48	0.18
AB028/96	7.77	0.06	7.97	0.11	2.57	1.60

Table 13 - Results for ^{241}Am

Sample	NPL Data		Analyst Data		Deviation (%)	u-test statistic
	^{241}Am Bq/kg	$\pm$ Bq/kg	^{241}Am Bq/kg	$\pm$ Bq/kg		
AB002/96(γ)	16.00	0.10	14.9	0.4	-6.88	2.67
AB003/96(α)	16.04	0.10	15	1	-6.48	1.04
AB006/96(α)	16.32	0.10	15.69	0.50	-3.87	1.24
AB007/96(α)	16.18	0.10	16.5	1.20	2.01	0.27
AB007/96(γ)	16.18	0.10	16.07	1.00	-0.65	0.11
AB008/96(γ)	15.92	0.10	17.2	2.1	8.06	0.62
AB008/96(α)	15.92	0.10	16.4	0.30	3.04	1.54
AB009/96(γ)	10.59	0.09	10.51	0.30	-0.74	0.26
AB009/96(γ)	10.59	0.09	9.94	0.27	-6.13	2.30
AB009/96(α)	10.59	0.09	9.73	0.62	-8.11	1.38
AB010/96(γ)	10.65	0.09	10.2	1.7	-4.21	0.27
AB011/96(α)	10.86	0.09	7.75	0.44	-28.64	6.94
AB011/96(γ)	10.86	0.09	10.24	1.90	-5.82	0.34
AB012/96(γ)	10.73	0.09	11.59	0.98	8.05	0.88
AB014/96(γ)	11.27	0.09	9.50	0.23	-15.68	7.18
AB017/96(α)	16.22	0.10	15.6	0.9	-3.81	0.69
AB017/96(γ)	16.22	0.10	15.2	0.8	-6.29	1.27
AB018/96(γ)	15.81	0.10	16	2	1.20	0.10
AB019/96(α)	16.35	0.10	18.5	1.1	13.22	1.72
AB022/96(α)	15.39	0.10	15.1	0.5	-1.89	0.58
AB024/96(γ)	15.93	0.10	18.8	1.6	18.03	1.80
AB025/96(α)	10.95	0.09	13	0.2	18.72	9.35
AB027/96(α)	10.25	0.09	10.04	0.28	-2.06	0.73
AB027/96(ICP-MS)	10.25	0.09	14.04	1.031	36.98	3.67
AB028/96(γ)	10.13	0.09	10.47	0.25	3.34	1.29

Table 14 - Results for ³H

Sample	NPL Data		Analyst Data		Deviation (%)	u-test statistic
	³ H Bq/kg	± Bq/kg	³ H Bq/kg	± Bq/kg		
AB001/96	786.5	7.7	819	42	4.13	0.77
AB002/96	771.1	7.6	732	29.9	-5.08	1.27
AB003/96	754.2	7.5	785	25	4.09	1.19
AB004/96	756.6	7.6	814.4	43.8	7.64	1.30
AB005/96	764.5	7.5	670	10	-12.36	7.56
AB006/96	776.4	7.7	813	32	4.71	1.12
AB011/96	1138.0	9.5	1206.37	58.48	6.01	1.16
AB012/96	1144.3	9.5	1179.9	14.6	3.11	2.05
AB015/96	1163.0	9.7	1018.3	21.3	-12.44	6.19
AB018/96	789.1	7.7	770	40	-2.41	0.48
AB019/96	772.6	7.7	760.2	6.6	-1.60	1.23
AB020/96	736.8	7.4	762	31	3.42	0.80
AB024/96	745.5	7.4	815	5	9.33	7.81
AB025/96	1136.6	9.5	1250	20	9.98	5.13
AB027/96	1140.0	9.5	1179.71	18.22	3.49	1.94
AB028/96	1095.5	9.1	935.5	24.5	-14.60	6.13
AB029/96	1128.5	9.4	1180	90	4.57	0.57
AB032/96	1144.3	9.5	1179.9	14.6	3.11	2.05

Table 15 - Results for ³⁵S

Sample	NPL Data		Analyst Data		Deviation (%)	u-test statistic
	³⁵ S Bq/kg	± Bq/kg	³⁵ S Bq/kg	± Bq/kg		
AB002/96	115.12	0.83	96.3	1.83	-16.35	9.39
AB006/96	116.29	0.84	134.0	9.6	15.22	1.84
AB011/96	76.52	0.68	74.60	8.07	-2.51	0.24
AB015/96	78.46	0.70	44.07	2.74	-43.83	12.17
AB021/96	111.62	0.81	109	11	-2.35	0.24

Table 16 - Results for ⁹⁰Sr

Sample	NPL Data		Analyst Data		Deviation (%)	u-test statistic
	⁹⁰ Sr Bq/kg	± Bq/kg	⁹⁰ Sr Bq/kg	± Bq/kg		
AB002/96	77.54	0.97	82.2	2.25	6.01	1.11
AB006/96	78.47	0.98	72.1	5.6	-8.11	1.12
AB007/96	77.01	0.97	74.7	2.0	-3.00	1.04
AB008/96	76.78	0.96	75.2	0.9	-2.06	1.21
AB011/96	115.97	1.32	86.38	6.53	-25.51	4.45
AB017/96	76.85	0.96	73	5	-5.01	0.76
AB022/96	74.74	0.94	68.5	5.3	-8.35	1.17
AB024/96	77.59	0.97	78.6	0.7	1.30	0.86
AB025/96	114.30	1.30	184.2	4	61.15	16.62

Table 17 - Results for ⁹⁹Tc

Sample	NPL Data		Analyst Data		Deviation (%)	u-test statistic
	⁹⁹ Tc Bq/kg	± Bq/kg	⁹⁹ Tc Bq/kg	± Bq/kg		
AB002/96	148.24	1.17	141	2.5	-4.89	2.63
AB010/96	96.77	0.92	91	8.7	-5.96	0.66
AB017/96	146.92	1.16	146	8	-0.63	0.12

Table 18 - Results for ^{57}Co (aqueous)

Sample	NPL Data		Analyst Data		Deviation (%)	u-test statistic
	^{57}Co Bq/kg	$\pm$ Bq/kg	^{57}Co Bq/kg	$\pm$ Bq/kg		
BG001/96	-	-	45.5	1.4	-	-
BG002/96	40.34	0.67	44.7	1.70	10.81	2.39
BG003/96	40.29	0.68	39.9	-	-0.97	-
BG004/96	41.61	0.68	41.2	2.0	-1.00	0.20
BG005/96	43.07	0.69	42.20	1.46	-2.01	0.54
BG007/96	41.68	0.69	43	3	3.16	0.43
BG008/96	40.55	0.67	45.48	-	12.17	-
BG009/96	40.13	0.67	41.82	1.50	4.22	1.04
BG010/96	42.85	0.69	48.5	1.3	13.18	3.85
BG021/96	44.66	0.70	36.1	1.5	-19.17	5.18
BG022/96	41.86	0.69	41.4	0.9	-1.10	0.41
BG024/96	42.12	0.69	44.54	5.3	5.75	0.99
BG025/96	41.37	0.68	42.7	2.3	3.21	0.55
BG026/96	40.48	0.68	44.8	5.0	10.68	0.86
BG027/96	41.93	0.69	42.1	4.55	0.40	0.04
BG028/96/1*	42.08	0.69	45.28	0.48	7.59	4.02
BG028/96/2*	42.08	0.69	44.14	0.31	4.88	2.73
BG029/96	39.88	0.68	42.1	5.6	5.57	0.40
BG030/96	40.61	0.67	39.80	0.38	-2.00	1.07
BG031/96	42.12	0.69	43.99	1.40	4.45	1.21
BG034/96	41.08	0.68	40.40	0.35	-1.65	0.88
BG035/96	41.60	0.70	47.4	0.3	13.95	7.70
BG038/96	42.13	0.69	43.7	1.1	3.73	1.22
BG039/96	41.34	0.69	43.5	2.0	5.23	1.03
BG040/96	41.81	0.69	49	5	17.21	1.43
BG041/96	45.04	0.69	50.19	0.45	11.43	6.28
BG042/96/1*	43.48	0.69	12.9	2.9	-70.33	10.27
BG042/96/2*	43.48	0.69	55.6	0.8	27.86	11.48
BG044/96	46.06	0.71	46.5	2.7	0.96	0.16
BG045/96	43.05	0.69	43.7	3.3	1.52	0.20
BG046/96	42.72	0.68	65	1.23	52.16	15.88
BG048/96	43.57	0.71	47.41	1.821	8.82	1.97
BG049/96/1*	42.87	0.70	35.14	0.68	-18.03	7.95
BG049/96/2*	42.87	0.70	40.21	0.78	-6.20	2.54
BG050/96	44.67	0.69	43.9	1.3	-1.73	0.53
BG051/96	44.05	0.69	48.2	2.9	9.41	1.40
BG052/96	42.31	0.69	45.3	2.0	7.07	1.42

* Laboratories 28, 42 and 49 submitted two sets of results for their samples; laboratories 28 and 42 each used two types of data analysis software whereas laboratory 49 used two different detectors. Their results for the other radionuclides in their samples are given in the relevant tables.

Table 19 - Results for ^{60}Co (aqueous)

Sample	NPL Data		Analyst Data		Deviation (%)	u-test statistic
	^{60}Co Bq/kg	$\pm$ Bq/kg	^{60}Co Bq/kg	$\pm$ Bq/kg		
BG001/96	42.07	0.61	41.2	1.3	-2.08	0.62
BG002/96	41.39	0.59	43.0	1.20	3.89	1.21
BG003/96	43.06	0.60	42.3	-	-1.77	-
BG004/96	41.40	0.60	42.8	0.6	3.38	1.66
BG005/96	38.24	0.60	42.03	2.28	9.92	1.61
BG007/96	41.90	0.60	40	3	-4.53	0.63
BG008/96	34.60	0.59	41.72	-	20.58	-
BG009/96	42.43	0.59	40.13	1.15	-5.42	1.79
BG010/96	42.61	0.60	43.2	1.2	1.39	0.45
BG021/96	44.37	0.60	45.0	1.5	1.43	0.39
BG022/96	42.92	0.61	42.1	0.9	-1.91	0.76
BG024/96	42.32	0.60	42.66	1.0	0.80	0.46
BG025/96	39.51	0.60	45.4	1.0	14.91	5.07
BG026/96	42.00	0.61	43.4	2.6	3.33	0.53
BG027/96	42.15	0.60	42.2	1.01	0.11	0.04
BG028/96/1	42.31	0.61	41.13	0.16	-2.78	1.89
BG028/96/2	42.31	0.61	41.21	0.24	-2.59	1.69
BG029/96	42.67	0.60	41.9	0.8	-1.80	0.78
BG030/96	41.26	0.59	41.96	0.40	1.71	1.00
BG031/96	41.90	0.60	40.55	1.97	-3.22	0.66
BG032/96	42.15	0.60	44.5	1.2	5.58	1.76
BG034/96	41.33	0.60	39.84	0.53	-3.60	1.86
BG035/96	42.28	0.61	41.2	0.5	-2.55	1.37
BG038/96	41.93	0.61	42.0	1.0	0.18	0.07
BG039/96	41.99	0.60	43.6	0.8	3.83	1.61
BG040/96	41.19	0.60	43	2.5	4.40	0.71
BG041/96	43.05	0.60	40.60	0.46	-5.70	3.28
BG042/96/1	41.96	0.60	36.1	2.1	-13.97	2.69
BG042/96/2	41.96	0.60	46.3	0.9	10.33	4.01
BG044/96	40.64	0.61	42.4	1.3	4.34	1.23
BG045/96	40.70	0.60	42.9	1.1	5.40	1.76
BG046/96	42.46	0.59	65	2.26	53.07	9.65
BG048/96	40.76	0.62	42.286	0.947	3.74	1.36
BG049/96/1	43.50	0.61	37.74	1.22	-13.24	4.23
BG049/96/2	43.50	0.61	41.18	1.03	-5.33	1.94
BG050/96	42.70	0.60	40.9	2.4	-4.21	0.73
BG051/96	40.85	0.60	41.8	3.4	2.33	0.28
BG052/96	40.83	0.61	43.3	1.0	6.05	2.11

Table 20 - Results for ^{125}Sb (aqueous)

Sample	NPL Data		Analyst Data		Deviation (%)	u-test statistic
	^{125}Sb Bq/kg	$\pm$ Bq/kg	^{125}Sb Bq/kg	$\pm$ Bq/kg		
BG001/96	34.69	0.53	36.1	1.6	4.06	0.84
BG002/96	33.12	0.48	45.6	2.97	37.68	4.15
BG003/96	33.79	0.48	36.4	-	7.73	-
BG004/96	33.46	0.48	34.8	1.0	4.00	1.21
BG005/96	34.95	0.48	34.45	2.68	-1.42	0.18
BG007/96	34.55	0.49	32	3	-7.38	0.62
BG008/96	39.34	0.48	54.29	-	38.00	-
BG009/96	33.63	0.48	31.56	1.50	-6.16	1.32
BG010/96	34.10	0.49	36.6	1.6	7.33	1.50
BG021/96	32.08	0.49	46.2	8.5	44.02	1.66
BG022/96	32.98	0.49	34.5	0.7	4.62	1.79
BG024/96	32.84	0.49	36.56	2.1	11.33	4.10
BG025/96	33.95	0.49	36.0	1.6	6.03	1.23
BG026/96	33.60	0.49	35.0	3.1	4.16	0.45
BG027/96	33.04	0.49	34.5	1.30	4.43	1.06
BG028/96/1	33.16	0.49	34.78	0.41	4.90	2.55
BG028/96/2	33.16	0.49	34.46	0.46	3.94	1.95
BG029/96	33.47	0.49	37.3	1.7	11.45	2.17
BG030/96	33.34	0.48	35.65	0.87	6.92	2.34
BG031/96	33.52	0.49	35.37	4.22	5.51	0.44
BG032/96	33.06	0.48	41.4	3.6	25.23	2.30
BG034/96	34.43	0.49	31.65	0.34	-8.07	4.68
BG035/96	34.51	0.50	37.3	1.3	8.07	2.01
BG038/96	33.88	0.49	35.5	1.4	4.78	1.10
BG039/96	34.28	0.49	35.3	1.7	2.98	0.58
BG040/96	35.34	0.49	30	2.5	-15.10	2.10
BG041/96	31.77	0.48	34.44	0.99	8.41	2.43
BG042/96/1	32.20	0.49	21.4	2.3	-33.55	4.60
BG042/96/2	32.20	0.49	31.0	1.7	-3.73	0.68
BG044/96	34.21	0.49	35.4	4	3.47	0.30
BG045/96	34.94	0.49	36.9	1.3	5.60	1.42
BG046/96	31.97	0.48	35	4.62	9.47	0.65
BG048/96	34.68	0.50	37.425	1.067	7.92	2.34
BG049/96/1	33.42	0.50	30.58	1.51	-8.51	1.80
BG049/96/2	33.42	0.50	33.35	0.94	-0.21	0.07
BG050/96	31.47	0.48	38.4	1.4	22.01	4.69
BG051/96	34.03	0.49	35.2	2.0	3.45	0.58
BG052/96	34.71	0.49	34.5	1.2	-0.61	0.17

Table 21 - Results for ^{134}Cs (aqueous)

Sample	NPL Data		Analyst Data		Deviation (%)	u-test statistic
	^{134}Cs Bq/kg	$\pm$ Bq/kg	^{134}Cs Bq/kg	$\pm$ Bq/kg		
BG001/96	26.91	0.44	23.4	0.8	-13.05	3.87
BG002/96	24.61	0.42	24.6	0.91	-0.03	0.07
BG003/96	25.92	0.43	28.3	-	9.17	-
BG004/96	25.67	0.43	25.3	0.5	-1.45	0.57
BG005/96	25.50	0.43	25.97	1.35	1.85	0.33
BG007/96	25.71	0.43	25	2	-2.75	0.35
BG008/96	25.54	0.43	24.79	-	-2.93	-
BG009/96	26.35	0.43	24.18	1	-8.24	2.00
BG010/96	26.18	0.43	26.2	0.8	0.10	0.03
BG021/96	26.48	0.43	29.4	2.5	11.04	1.15
BG022/96	26.09	0.43	27.7	1.7	6.16	0.92
BG024/96	26.26	0.43	26.83	1.3	2.18	1.04
BG025/96	26.60	0.43	25.4	1.2	-4.52	0.95
BG026/96	26.32	0.43	25.5	1.7	-3.11	0.47
BG027/96	26.41	0.44	27.8	1.03	5.25	1.25
BG028/96/1	26.51	0.44	25.83	0.46	-2.56	1.08
BG028/96/2	26.51	0.44	26.68	0.35	0.65	0.31
BG029/96	27.03	0.43	24.2	0.5	-10.47	4.30
BG030/96	26.12	0.43	24.07	0.30	-7.85	3.99
BG031/96	26.25	0.43	23.76	1.71	-9.50	1.42
BG032/96	16.16	0.43	22.0	0.9	-15.91	4.19
BG034/96	26.70	0.43	23.83	0.32	-10.64	5.29
BG035/96	27.60	0.44	23.3	0.3	-15.57	8.08
BG038/96	27.09	0.44	27.6	0.9	1.89	0.52
BG039/96	25.22	0.43	26.6	0.9	5.49	1.40
BG040/96	24.96	0.43	30	2	20.18	2.47
BG041/96	26.48	0.43	24.70	0.35	-6.72	3.24
BG042/96/1	26.57	0.43	5.4	0.8	-79.68	23.32
BG042/96/2	26.57	0.43	28.3	1.0	6.52	1.59
BG044/96	26.52	0.44	25.5	1.6	-3.86	0.62
BG045/96	25.75	0.43	23.8	1.1	-7.56	1.65
BG046/96	26.10	0.43	25	3.19	-4.22	0.35
BG048/96	26.89	0.44	26.803	0.662	-0.31	0.11
BG049/96/1	27.00	0.44	25.63	0.86	-5.08	1.43
BG049/96/2	27.00	0.44	27.89	0.69	3.30	1.09
BG050/96	26.79	0.43	23.6	2.1	-11.90	1.49
BG051/96	25.85	0.43	25.9	1.1	0.21	0.05
BG052/96	26.38	0.44	28.0	1.0	6.14	1.49

Table 22 - Results for ^{137}Cs (aqueous)

Sample	NPL Data		Analyst Data		Deviation (%)	u-test statistic
	^{137}Cs Bq/kg	$\pm$ Bq/kg	^{137}Cs Bq/kg	$\pm$ Bq/kg		
BG001/96	34.29	0.54	34.3	1.1	0.03	0.01
BG002/96	34.06	0.53	33.3	1.04	-2.23	0.66
BG003/96	35.08	0.54	35.2	-	0.33	-
BG004/96	34.41	0.54	31.4	0.5	-8.74	4.13
BG005/96	33.87	0.54	31.38	1.98	-7.35	1.22
BG007/96	34.82	0.54	32	2	-8.11	1.37
BG008/96	33.90	0.53	31.21	-	-7.93	-
BG009/96	33.24	0.53	32.09	1.27	-3.46	0.84
BG010/96	34.04	0.54	36.0	1.1	5.75	1.61
BG021/96	34.78	0.54	39.0	1.9	12.15	2.14
BG022/96	34.63	0.54	35.5	0.7	2.51	0.99
BG024/96	34.49	0.54	33.83	1.5	-1.79	0.84
BG025/96	34.23	0.54	36.5	1.3	6.63	1.62
BG026/96	32.87	0.54	35.4	2.2	7.68	1.12
BG027/96	34.35	0.54	35.5	0.95	3.34	1.05
BG028/96/1	33.79	0.54	33.64	0.49	-0.46	0.22
BG028/96/2	33.79	0.54	34.29	0.40	1.47	0.74
BG029/96	33.42	0.54	35.7	0.8	6.83	2.38
BG030/96	32.96	0.53	35.63	0.46	8.11	3.86
BG031/96	34.82	0.54	33.38	1.65	-4.14	0.84
BG032/96	33.68	0.53	38.4	1.8	14.03	2.52
BG034/96	34.71	0.54	31.94	0.49	-7.98	3.80
BG035/96	33.77	0.55	35.1	0.3	3.94	2.15
BG038/96	33.15	0.54	34.2	0.9	3.18	1.01
BG039/96	34.56	0.54	34.6	0.9	0.12	0.04
BG040/96	35.61	0.54	34	2	-4.51	0.78
BG041/96	35.07	0.54	33.66	0.37	-4.03	2.18
BG042/96/1	34.54	0.54	36.3	2.6	5.10	0.67
BG042/96/2	34.54	0.54	31.7	1.1	-8.22	2.32
BG044/96	35.18	0.55	34.8	1.7	-1.08	0.22
BG045/96	33.86	0.54	34.6	1.6	2.19	0.44
BG046/96	34.26	0.53	35	2.33	2.15	0.31
BG048/96	35.66	0.56	36.238	0.873	1.62	0.56
BG049/96/1	35.44	0.58	28.38	0.97	-19.93	6.27
BG049/96/2	35.44	0.58	32.15	0.87	-9.28	3.15
BG050/96	32.12	0.54	33.8	0.8	-0.93	0.34
BG051/96	34.30	0.54	35.7	1.9	4.07	0.71
BG052/96	33.97	0.54	34.4	1.0	1.27	0.38

Table 23 - Results for ^{154}Eu (aqueous)

Sample	NPL Data		Analyst Data		Deviation (%)	u-test statistic
	^{154}Eu Bq/kg	$\pm$ Bq/kg	^{154}Eu Bq/kg	$\pm$ Bq/kg		
BG001/96	24.35	0.39	25.4	1.3	4.31	0.78
BG002/96	24.41	0.38	22.2	1.88	-9.05	1.16
BG003/96	23.48	0.38	24.5	-	4.36	-
BG004/96	23.96	0.38	24.6	1.0	2.67	0.60
BG005/96	23.81	0.38	20.59	1.54	-13.52	2.04
BG007/96	23.34	0.38	22	3	-5.74	0.45
BG009/96	23.60	0.38	22.46	1.13	-4.83	0.96
BG010/96	24.17	0.39	26.4	1.2	9.23	1.77
BG021/96	22.78	0.38	29.6	5.5	29.94	1.24
BG022/96	24.59	0.39	22.2	0.6	-9.72	3.34
BG024/96	24.01	0.39	23.68	5.2	-1.37	0.07
BG025/96	22.89	0.38	22.0	1.3	-3.89	0.66
BG026/96	25.26	0.39	24.9	2.4	-1.43	0.15
BG027/96	22.96	0.38	22.9	1.90	-0.26	0.04
BG028/96/1	24.96	0.39	23.33	0.32	-6.53	3.24
BG028/96/2	24.96	0.39	22.11	0.25	-11.42	6.16
BG029/96	24.45	0.39	23.6	3.2	-3.48	0.27
BG030/96	23.64	0.38	26.55	0.59	12.31	4.15
BG031/96	23.29	0.38	24.08	4.23	3.39	0.19
BG032/96	23.91	0.38	27.7	2.9	15.85	1.30
BG034/96	24.17	0.38	21.44	0.28	-11.29	5.79
BG035/96	24.72	0.39	25.5	1.1	3.16	0.67
BG038/96	24.75	0.39	24.1	0.8	-2.63	0.74
BG039/96	23.34	0.39	24.3	1.4	4.11	0.67
BG040/96	23.84	0.38	18	2	-24.50	2.87
BG041/96	23.96	0.38	23.67	0.77	-1.21	0.34
BG042/96/1	23.57	0.39	21.7	5.5	-7.93	0.34
BG042/96/2	23.57	0.39	18.9	1.6	-19.81	2.84
BG044/96	24.02	0.39	25.1	2.3	4.50	0.47
BG045/96	24.04	0.39	25.8	1.4	7.32	1.22
BG046/96	22.69	0.38	25	13.49	10.18	0.18
BG048/96	25.07	0.40	24.198	0.832	-3.48	0.95
BG049/96/1	24.44	0.39	24.59	1.17	0.61	0.13
BG049/96/2	24.44	0.39	24.85	0.85	1.68	0.44
BG050/96	24.46	0.73	34.7	3.7	41.86	2.72
BG051/96	23.41	0.38	22.9	2.0	-2.18	0.26
BG052/96	23.88	0.39	24.0	1.2	0.50	0.10

Table 24 - Results for ^{155}Eu (aqueous)

Sample	NPL Data		Analyst Data		Deviation (%)	u-test statistic
	^{155}Eu Bq/kg	$\pm$ Bq/kg	^{155}Eu Bq/kg	$\pm$ Bq/kg		
BG001/96	38.76	0.74	37.7	1.9	-2.73	0.52
BG002/96	36.99	0.71	38.9	2.53	5.16	0.73
BG003/96	39.66	0.74	39.2	-	-1.16	-
BG004/96	38.90	0.73	38.5	1.0	-1.03	0.33
BG005/96	37.90	0.73	39.21	2.66	3.46	0.48
BG007/96	38.60	0.73	39	3	1.04	0.13
BG008/96	39.08	0.73	37.45	-	-4.17	-
BG009/96	38.33	0.72	32.20	1.20	-15.99	4.39
BG010/96	40.01	0.74	45.9	2.2	14.69	2.54
BG021/96	41.26	0.74	42.1	2.3	2.04	0.35
BG022/96	38.37	0.73	39.6	0.8	3.21	1.14
BG024/96	37.82	0.73	36.87	1.6	-2.51	0.55
BG025/96	38.69	0.73	42.7	1.6	10.36	2.29
BG026/96	38.69	0.74	39.3	3.0	1.58	0.20
BG027/96	39.61	0.74	45.0	1.90	13.61	2.65
BG028/96/1	38.58	0.74	38.94	0.94	0.93	0.31
BG028/96/2	38.58	0.74	39.14	0.57	1.45	0.60
BG029/96	38.53	0.73	45.2	6.1	17.31	1.09
BG030/96	37.24	0.71	39.12	0.52	5.05	2.14
BG031/96	40.52	0.74	36.58	1.98	-9.72	1.87
BG032/96	36.92	0.72	64.2	3.1	73.89	8.58
BG034/96	38.07	0.73	33.49	0.35	-12.03	5.67
BG035/96	39.33	0.75	46.8	0.5	18.99	8.29
BG038/96	38.23	0.74	42.0	1.4	9.86	2.39
BG039/96	40.22	0.74	38.2	1.1	-5.02	1.53
BG040/96	39.10	0.74	33	3	-15.60	1.98
BG041/96	37.75	0.72	42.57	0.94	12.77	4.08
BG042/96/1	39.04	0.74	13.5	1.3	-65.42	17.08
BG042/96/2	39.04	0.74	38.5	1.9	-1.38	0.27
BG044/96	39.38	0.74	41.4	3.3	5.13	0.60
BG045/96	37.10	0.73	43.9	2.0	18.33	3.20
BG046/96	39.87	0.73	43	4.12	7.85	0.75
BG048/96	37.94	0.74	38.039	0.955	0.26	0.09
BG049/96/1	39.67	0.75	32.07	1.19	-19.16	5.41
BG049/96/2	39.67	0.75	36.02	1.11	-9.21	2.73
BG050/96	38.94	0.73	34.4	1.3	-11.66	3.05
BG051/96	37.24	0.72	42.4	2.6	13.86	1.92
BG052/96	38.38	0.74	38.932	3.0	1.44	0.18

Table 25 - Results for ^{57}Co (milk)

Sample	NPL Data		Analyst Data		Deviation (%)	u-test statistic
	^{57}Co Bq/kg	$\pm$ Bq/kg	^{57}Co Bq/kg	$\pm$ Bq/kg		
BGM001/96	61.81	0.77	52.8	1.51	-14.58	5.33
BGM007/96	68.76	0.79	61.6	1.2	10.42	5.00
BGM008/96	73.76	0.81	78.8	7.4	6.84	0.68
BGM009/96	79.29	0.85	82.7	1.5	4.30	1.98
BGM011/96	60.56	0.76	50.62	0.48	-16.41	11.10
BGM012/96	33.79	0.66	26.56	0.55	-21.39	8.43
BGM014/96	38.63	0.68	36.97	0.33	-4.21	2.20
BGM015/96	46.54	0.71	54.3	2.1	16.68	3.51
BGM016/96	38.84	0.69	45.3	0.4	16.64	8.12
BGM018/96	47.24	0.71	51	3	7.96	1.22
BGM019/96	43.53	0.70	58.5	5.9	34.39	2.53
BGM020/96	45.43	0.71	46.6	1.24	2.59	0.83
BGM021/96	46.77	0.71	46.4	1.2	-0.79	0.27
BGM022/96	34.40	0.67	60	1.15	74.43	19.24
BGM023/96	44.14	0.70	55.865	2.816	26.56	4.04
BGM024/96	99.06	0.94	88	7	-11.16	1.57
BGM025/96	45.88	0.71	42.8	1.58	-6.71	1.78

Table 26 - Results for ^{60}Co (milk)

Sample	NPL Data		Analyst Data		Deviation (%)	u-test statistic
	^{60}Co Bq/kg	$\pm$ Bq/kg	^{60}Co Bq/kg	$\pm$ Bq/kg		
BGM001/96	46.44	0.61	48.9	0.65	5.29	2.76
BGM007/96	55.02	0.61	50.1	1.0	-8.94	4.21
BGM008/96	34.96	0.60	37.4	2.3	6.98	1.03
BGM009/96	52.15	0.62	52.4	1.0	0.47	0.21
BGM011/96	57.16	0.62	53.75	0.46	-5.97	4.46
BGM012/96	66.05	0.61	49.90	0.96	-24.45	14.23
BGM013/96	59.74	0.62	57.8	3.1	-3.25	0.62
BGM014/96	28.81	0.61	27.02	0.44	-6.20	2.40
BGM015/96	37.21	0.61	39.0	0.9	4.80	1.65
BGM016/96	39.64	0.62	38.7	0.5	-2.36	1.19
BGM018/96	46.01	0.61	50	2	8.66	1.91
BGM019/96	39.46	0.61	50.1	2.5	26.96	4.14
BGM020/96	47.67	0.61	48.7	0.44	2.16	1.38
BGM021/96	88.99	0.61	89.4	2.1	0.46	0.19
BGM022/96	51.92	0.62	51	1.78	-1.78	0.50
BGM023/96	53.25	0.62	57.058	1.255	7.16	2.73
BGM024/96	42.06	0.61	41	3	-2.53	0.35
BGM025/96	51.09	0.62	50.9	2.93	-0.36	0.07

Table 27 - Results for ^{125}Sb (milk)

Sample	NPL Data		Analyst Data		Deviation (%)	u-test statistic
	^{125}Sb Bq/kg	$\pm$ Bq/kg	^{125}Sb Bq/kg	$\pm$ Bq/kg		
BGM001/96	38.26	0.54	54.6	1.67	42.71	9.32
BGM007/96	42.86	0.49	43.1	0.9	0.57	0.24
BGM008/96	58.45	0.49	64.0	5.0	9.49	1.11
BGM009/96	32.81	0.50	33.3	1.2	1.51	0.39
BGM011/96	34.13	0.50	35.52	1.44	4.08	0.92
BGM012/96	24.91	0.49	23.81	1.81	-4.43	0.59
BGM013/96	42.15	0.50	43.6	2.1	3.44	0.68
BGM014/96	35.27	0.49	32.06	0.48	-9.11	4.70
BGM015/96	30.38	0.50	30.9	1.3	1.71	0.38
BGM016/96	35.87	0.50	40.1	1.7	11.78	2.39
BGM018/96	40.00	0.50	43	5	7.50	0.60
BGM019/96	36.72	0.49	51.1	4.1	39.17	3.49
BGM020/96	34.05	0.50	35.9	0.57	5.43	2.46
BGM021/96	34.76	0.50	35.0	1.4	0.69	0.17
BGM022/96	39.96	0.50	43	3.77	7.62	0.81
BGM023/96	36.86	0.49	43.466	1.213	17.92	5.05
BGM024/96	30.18	0.50	27	3	-10.52	1.05
BGM025/96	37.88	0.50	37.4	1.60	-1.27	0.29

Table 28 - Results for ^{134}Cs (milk)

Sample	NPL Data		Analyst Data		Deviation (%)	u-test statistic
	^{134}Cs Bq/kg	$\pm$ Bq/kg	^{134}Cs Bq/kg	$\pm$ Bq/kg		
BGM001/96	37.82	0.48	37.4	0.56	-1.11	0.58
BGM007/96	52.63	0.54	59.2	3.6	12.48	1.81
BGM008/96	41.24	0.49	40.2	2.4	-2.31	0.43
BGM009/96	24.55	0.44	27.1	0.6	-10.00	3.33
BGM011/96	22.83	0.43	16.49	0.36	-27.78	11.42
BGM012/96	32.20	0.45	27.40	0.93	-14.90	4.65
BGM013/96	30.64	0.45	29.3	1.5	-4.37	0.86
BGM014/96	23.50	0.43	21.21	0.29	-9.75	4.47
BGM015/96	35.18	0.47	34.6	0.8	-1.64	0.63
BGM016/96	28.12	0.45	25.8	0.3	-8.25	4.34
BGM018/96	29.48	0.45	27	2	-8.41	1.21
BGM019/96	29.08	0.45	34.2	1.7	17.61	2.92
BGM020/96	31.95	0.46	31.5	0.70	-1.40	0.54
BGM021/96	29.46	0.45	29.2	0.9	-0.88	0.26
BGM022/96	30.83	0.45	29	2.78	-5.95	0.66
BGM023/96	31.14	0.45	33.622	0.8	7.97	2.70
BGM024/96	27.45	0.44	25	2	-8.94	1.20
BGM025/96	30.29	0.45	27.2	2.62	-10.19	1.17

Table 29 - Results for ^{137}Cs (milk)

Sample	NPL Data		Analyst Data		Deviation (%)	u-test statistic
	^{137}Cs Bq/kg	$\pm$ Bq/kg	^{137}Cs Bq/kg	$\pm$ Bq/kg		
BGM001/96	63.94	0.67	64.4	0.67	0.71	0.49
BGM007/96	52.87	0.61	56.5	1.1	6.87	2.90
BGM008/96	21.07	0.51	22.2	1.5	5.36	0.72
BGM009/96	62.78	0.66	64.0	1.3	1.94	0.84
BGM011/96	50.60	0.61	49.19	0.59	-2.78	1.71
BGM012/96	55.99	0.62	52.85	0.85	-5.61	2.99
BGM013/96	41.32	0.57	41.8	2.4	1.17	0.20
BGM014/96	59.82	0.65	58.46	0.83	-2.27	1.30
BGM015/96	28.30	0.56	28.4	0.6	0.35	0.13
BGM016/96	34.41	0.55	36.2	0.4	5.19	2.64
BGM018/96	32.66	0.54	33	2	1.04	0.17
BGM019/96	34.58	0.55	46.1	2.2	33.32	5.09
BGM020/96	37.43	0.56	38.0	0.39	1.52	0.84
BGM021/96	36.76	0.56	37.5	1.0	2.01	0.65
BGM022/96	30.91	0.54	33	2.10	6.77	0.97
BGM023/96	51.90	0.61	60.967	1.378	17.46	6.02
BGM024/96	31.20	0.54	31	2	-0.63	0.10
BGM025/96	41.91	0.57	41.8	0.92	-0.26	0.10

Table 30 - Results for ^{154}Eu (milk)

Sample	NPL Data		Analyst Data		Deviation (%)	u-test statistic
	^{154}Eu Bq/kg	$\pm$ Bq/kg	^{154}Eu Bq/kg	$\pm$ Bq/kg		
BGM001/96	24.89	0.39	28.4	1.07	14.10	3.09
BGM007/96	25.73	0.39	13.4	1.1	-47.92	10.57
BGM008/96	31.54	0.42	38.2	3.2	21.12	2.07
BGM009/96	22.07	0.39	25.6	1.1	15.99	3.03
BGM011/96	30.97	0.42	33.08	0.73	6.81	2.51
BGM012/96	34.62	0.43	15.86	1.30	-54.19	13.70
BGM013/96	29.29	0.41	32.0	3.6	9.25	0.75
BGM014/96	17.54	0.37	15.93	0.25	-9.18	3.61
BGM015/96	25.72	0.40	26.6	1.3	3.42	0.65
BGM016/96	26.88	0.40	28.6	1.5	6.40	1.11
BGM018/96	28.53	0.41	41	4	43.71	3.11
BGM019/96	26.96	0.40	35.2	5.3	30.56	1.55
BGM020/96	24.39	0.39	22.3	2.00	-8.57	1.03
BGM021/96	23.67	0.39	24.2	0.8	2.24	0.60
BGM022/96	24.86	0.39	27	10.02	8.61	0.22
BGM023/96	21.75	0.38	24.081	0.898	10.72	2.39
BGM024/96	21.69	0.38	25	2	15.26	1.63
BGM025/96	29.46	0.41	26.4	2.80	-10.39	1.09

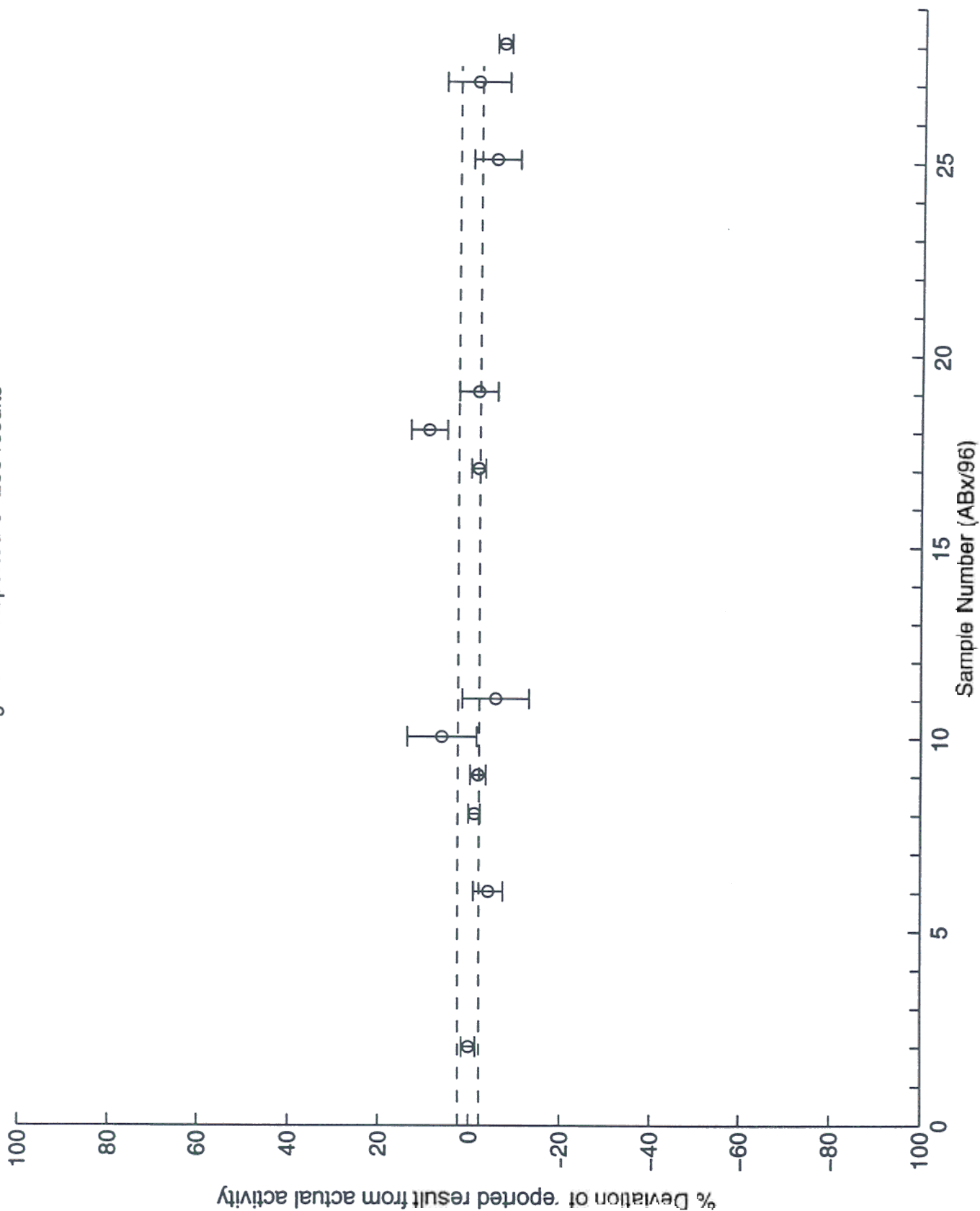
Table 31 - Results for ¹⁵⁵Eu (milk)

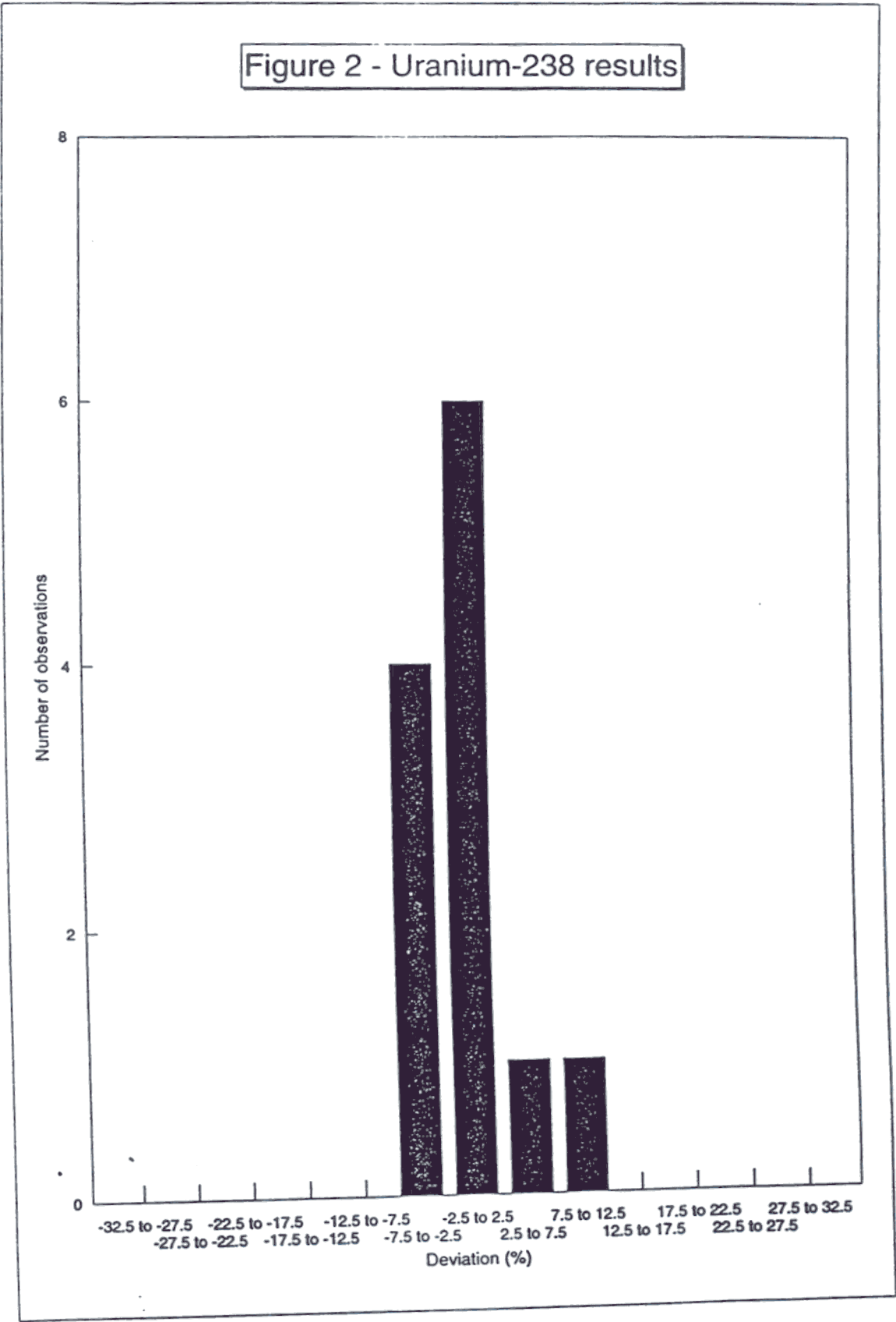
Sample	NPL Data		Analyst Data		Deviation (%)	u-test statistic
	¹⁵⁵ Eu Bq/kg	± Bq/kg	¹⁵⁵ Eu Bq/kg	± Bq/kg		
BGM001/96	74.95	0.94	79.6	1.50	6.20	2.63
BGM007/96	46.03	0.77	30.3	3.0	-34.17	5.08
BGM008/96	46.94	0.77	48.2	4.0	2.68	0.31
BGM009/96	42.53	0.76	49.5	2.2	16.39	3.00
BGM011/96	25.54	0.70	29.07	1.11	13.82	2.69
BGM012/96	36.58	0.72	11.29	0.76	-69.14	24.16
BGM013/96	31.44	0.72	25.1	2.4	-20.17	2.53
BGM014/96	39.80	0.74	35.90	0.41	-9.80	4.62
BGM015/96	32.70	0.72	33.1	1.2	1.19	0.28
BGM016/96	40.48	0.76	41.2	0.7	1.78	0.70
BGM018/96	45.91	0.47	66	6	43.76	3.34
BGM019/96	39.48	0.74	47.1	9.4	19.30	0.81
BGM020/96	39.20	0.77	44.6	0.71	13.78	5.16
BGM021/96	38.83	0.74	42.6	1.5	9.71	2.26
BGM022/96	32.53	0.72	44	2.81	35.26	3.96
BGM023/96	41.59	0.75	46.817	1.081	12.57	3.98
BGM024/96	37.57	0.74	41	3	9.13	1.11
BGM025/96	49.41	0.79	41.5	2.12	-16.01	3.50

Table 32 - Other reported radionuclides

Sample identifier	Radionuclide	Reported activity concentration (Bq/kg)	Overall uncertainty (Bq/kg)
BG008/96	²² Na	9.78	1.17
AB008/96	^{114m} In	731.3	43.4
BG032/96	⁴⁶ Sc	30.2	1.9
AB014/96	²³⁴ Th	6.4	1.0
	Gross α	16	6
	Gross β	230	90

Figure 1 – Reported U-238 results





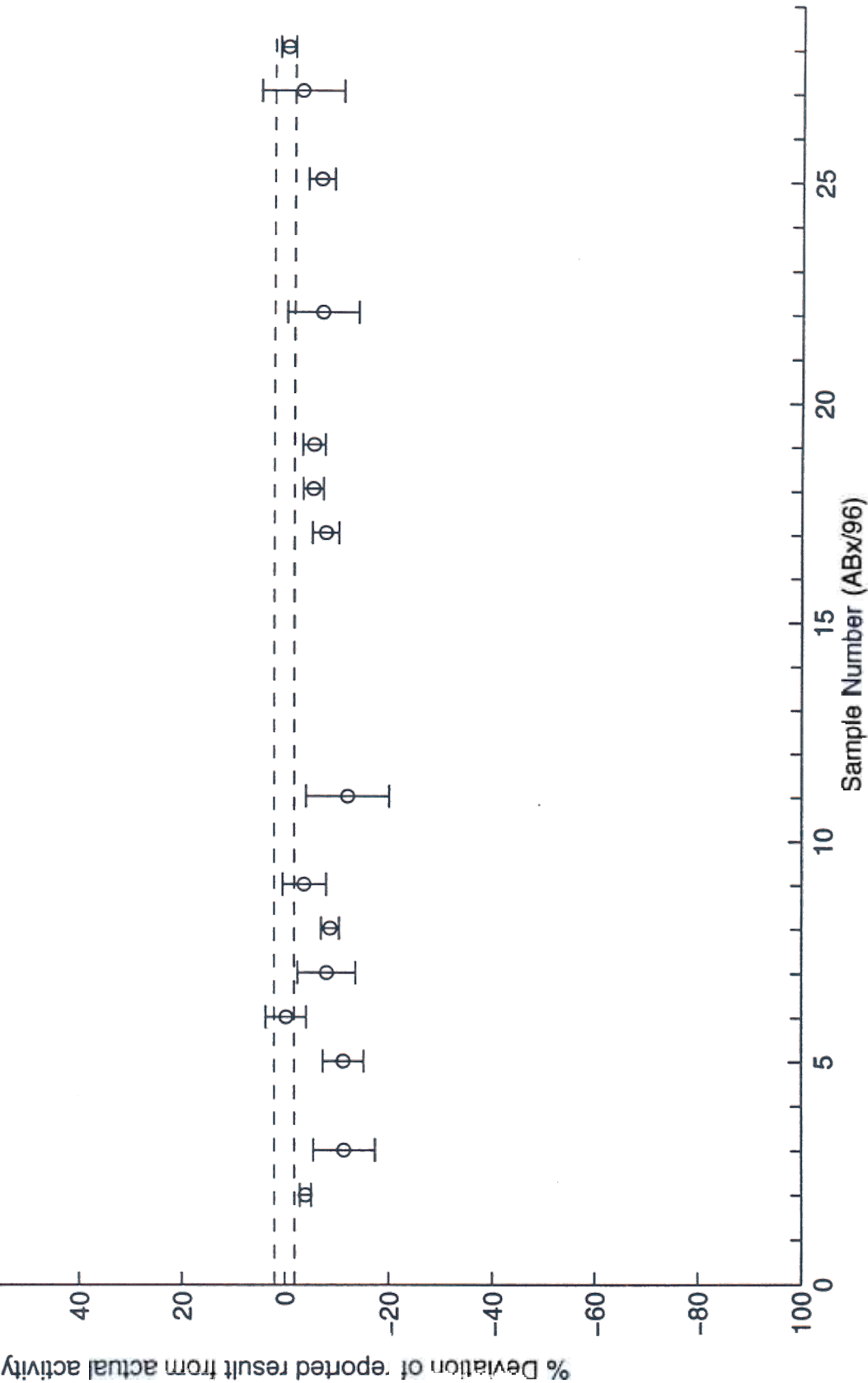


Figure 3 – Reported Pu-238 results

Figure 4 - Plutonium-238 results

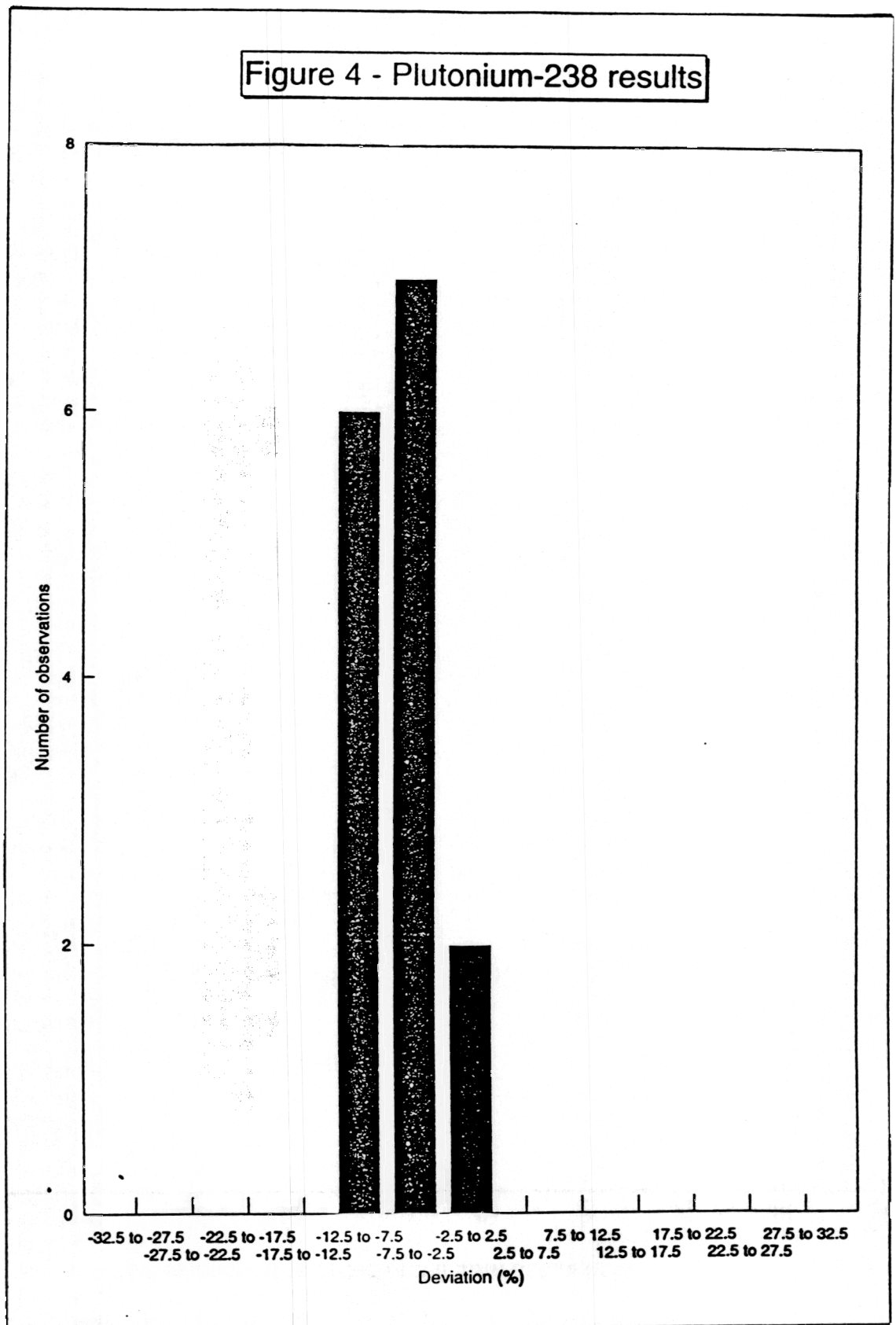


Figure 5 – Reported (Pu-239 + Pu-240) results

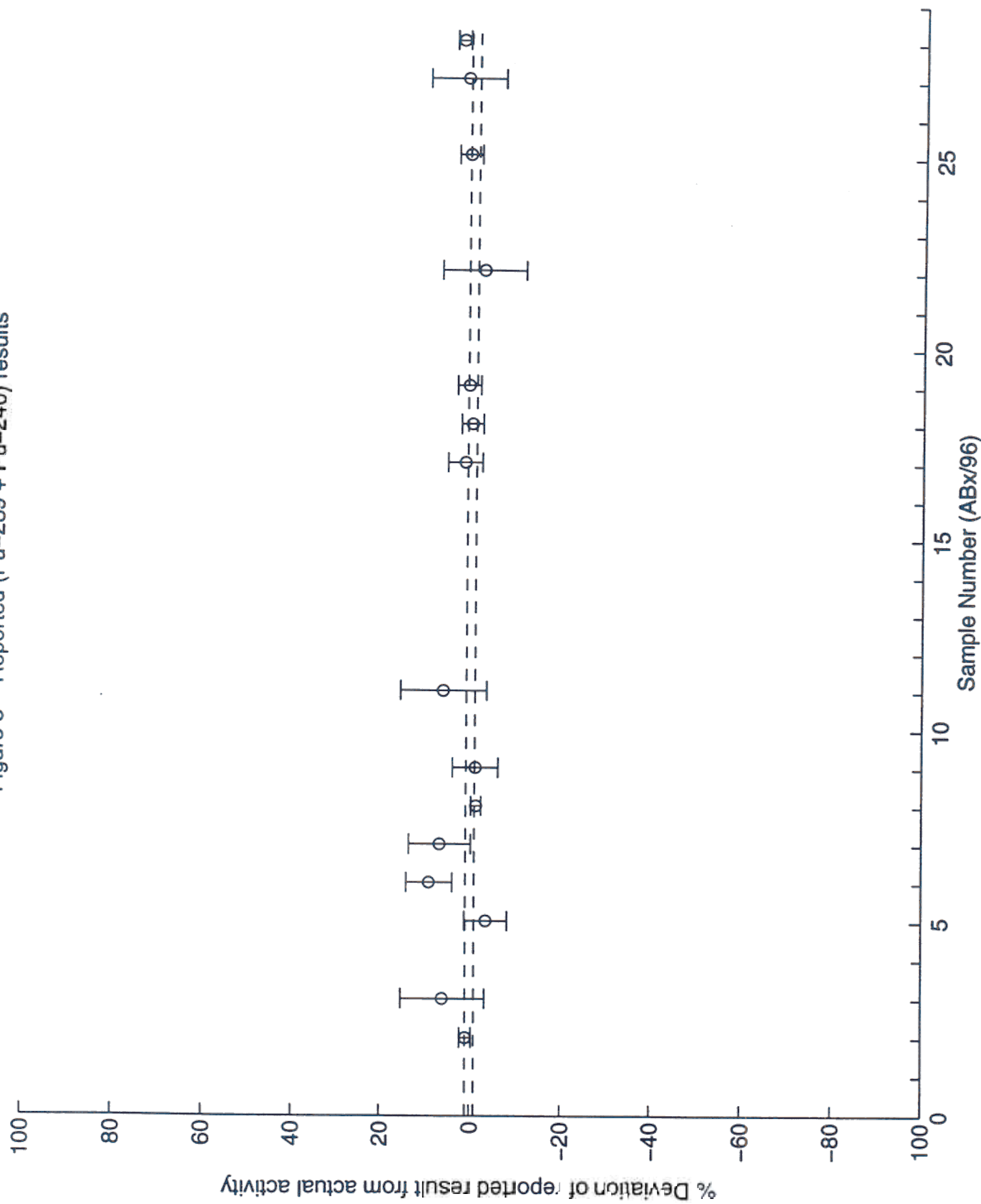


Figure 6 - Plutonium-239 + Plutonium-240 results

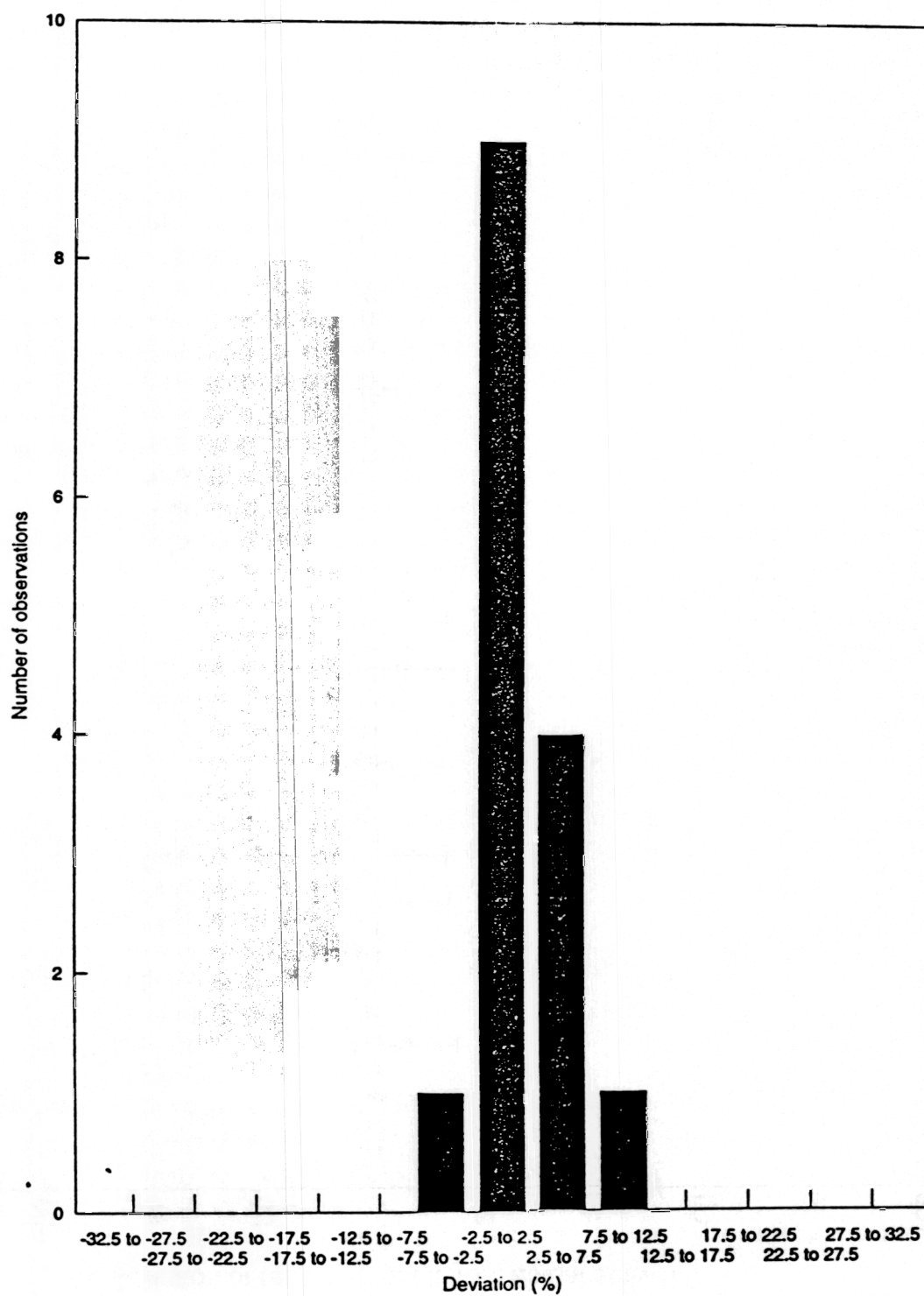


Figure 7 – Reported Am-241 results (gamma spectrometry)

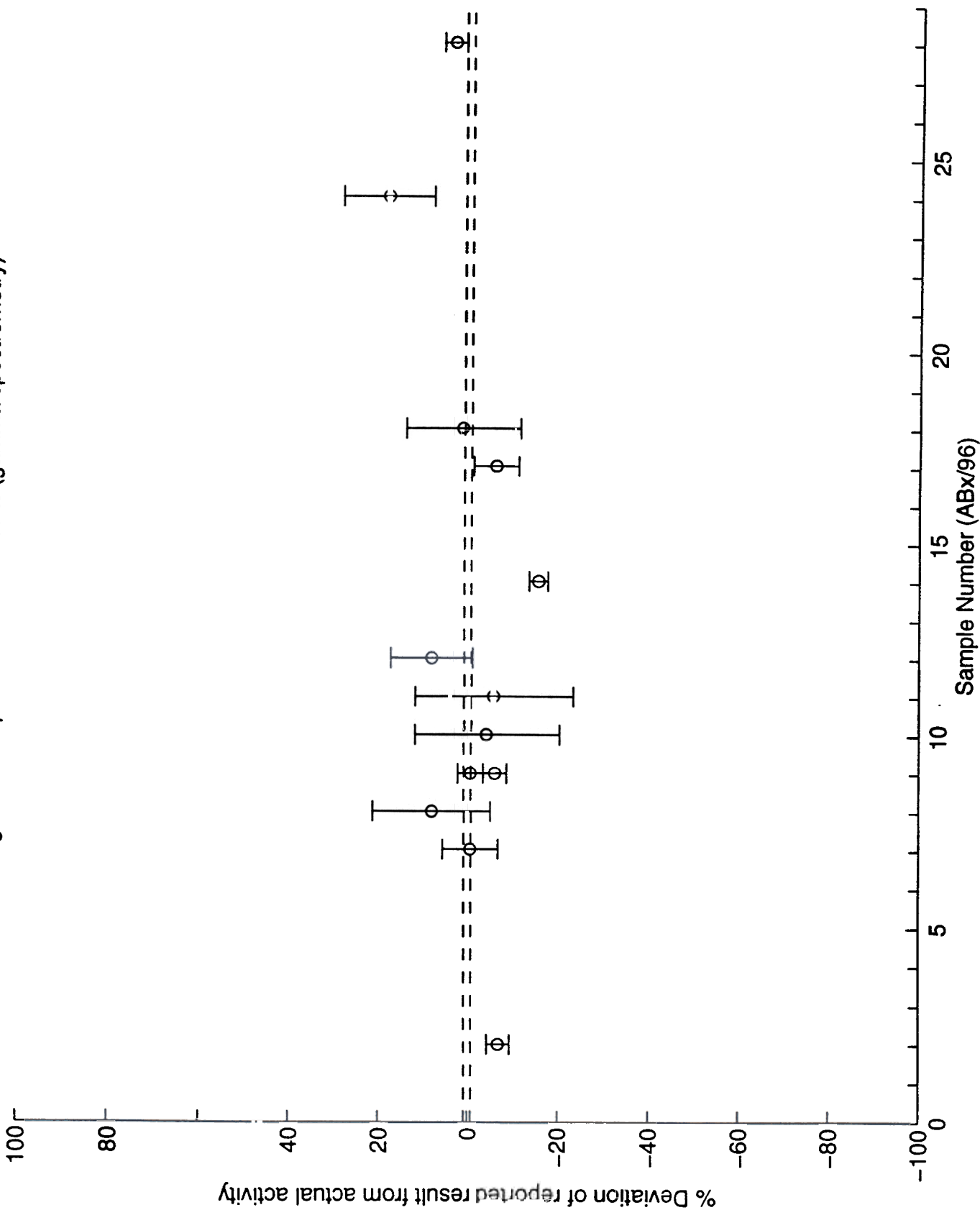


Figure 8 - Americium-241 gamma spectrometry results

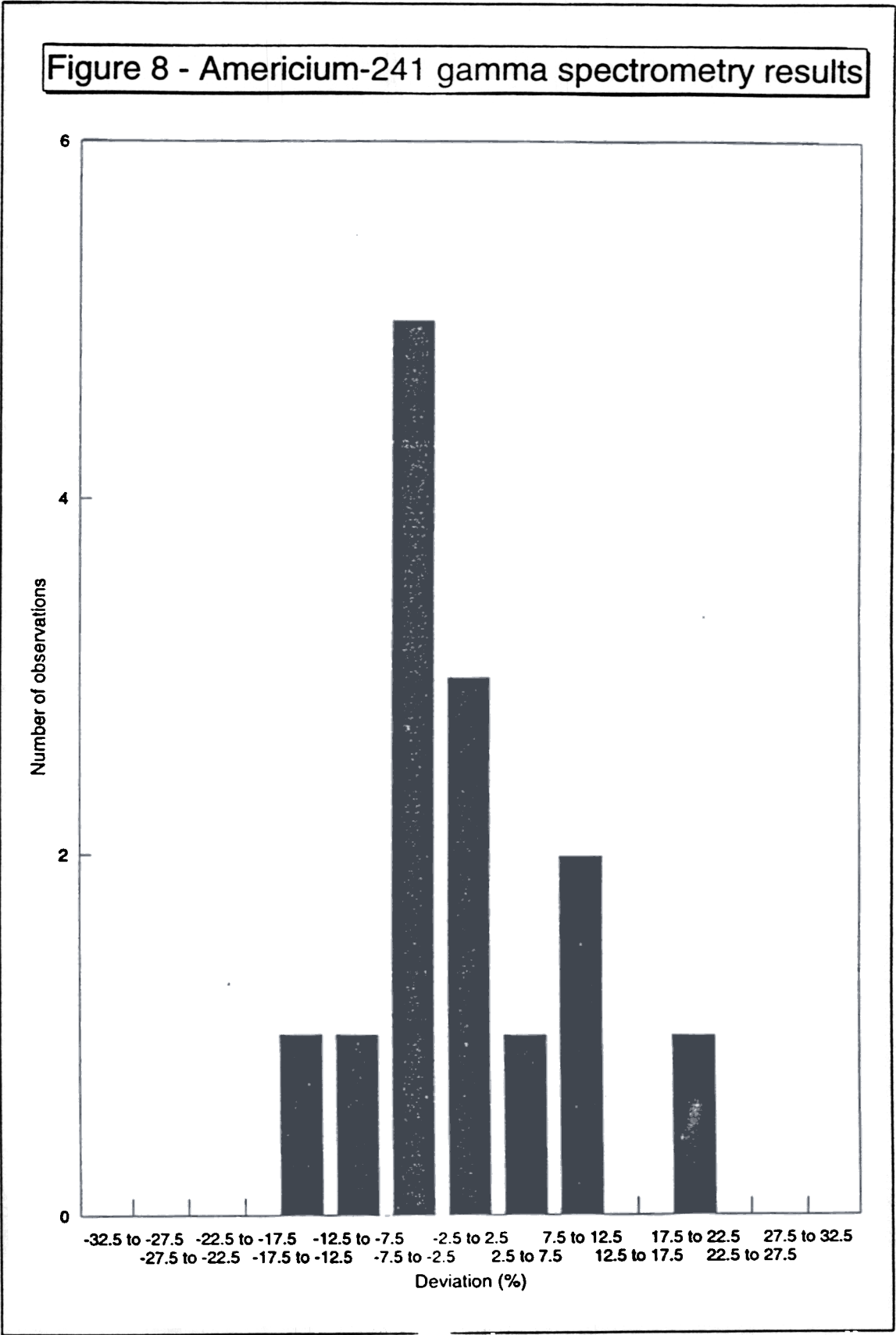


Figure 9 -- Reported Am-241 results (radiochemistry)

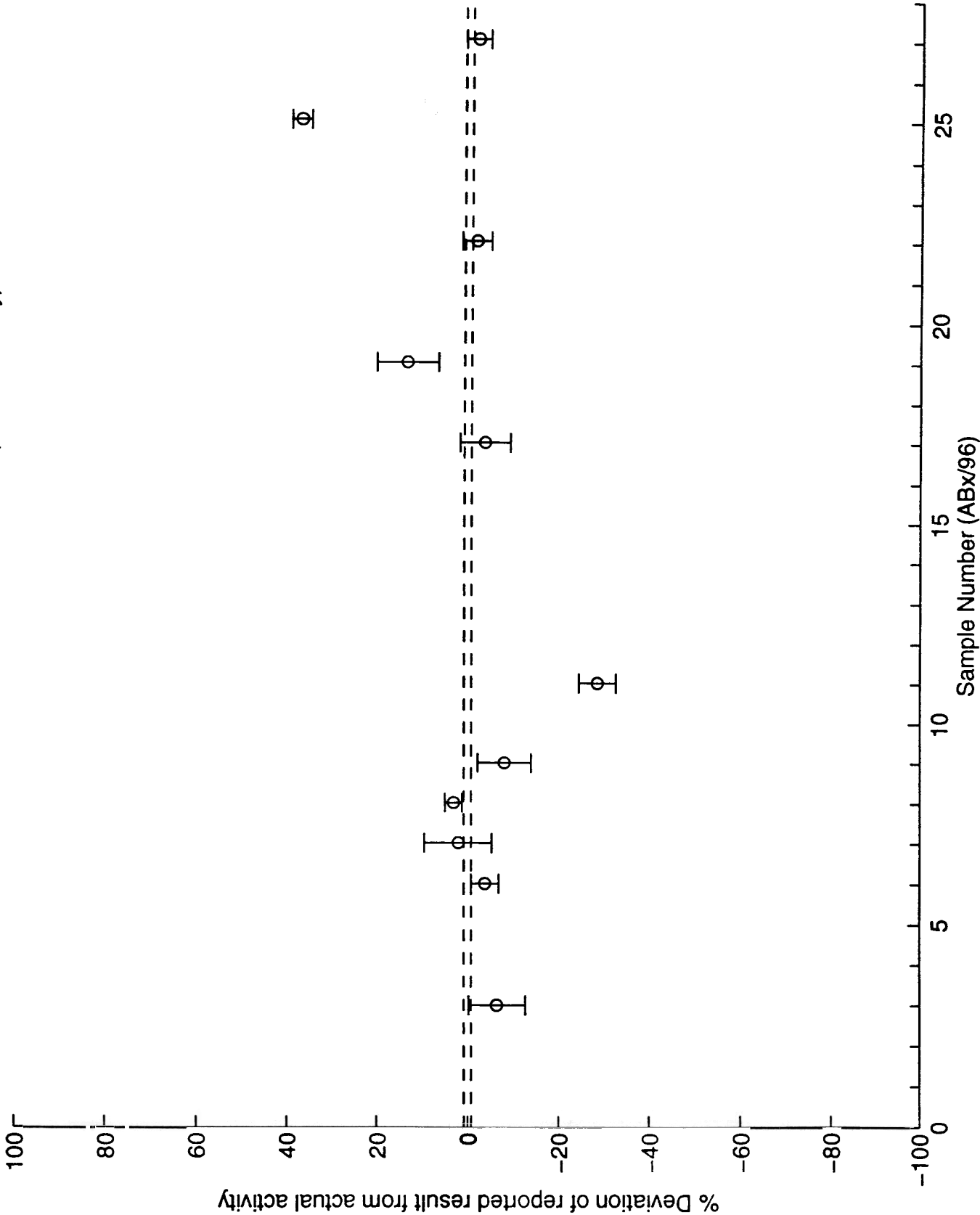


Figure 10 - Americium-241 radiochemistry results

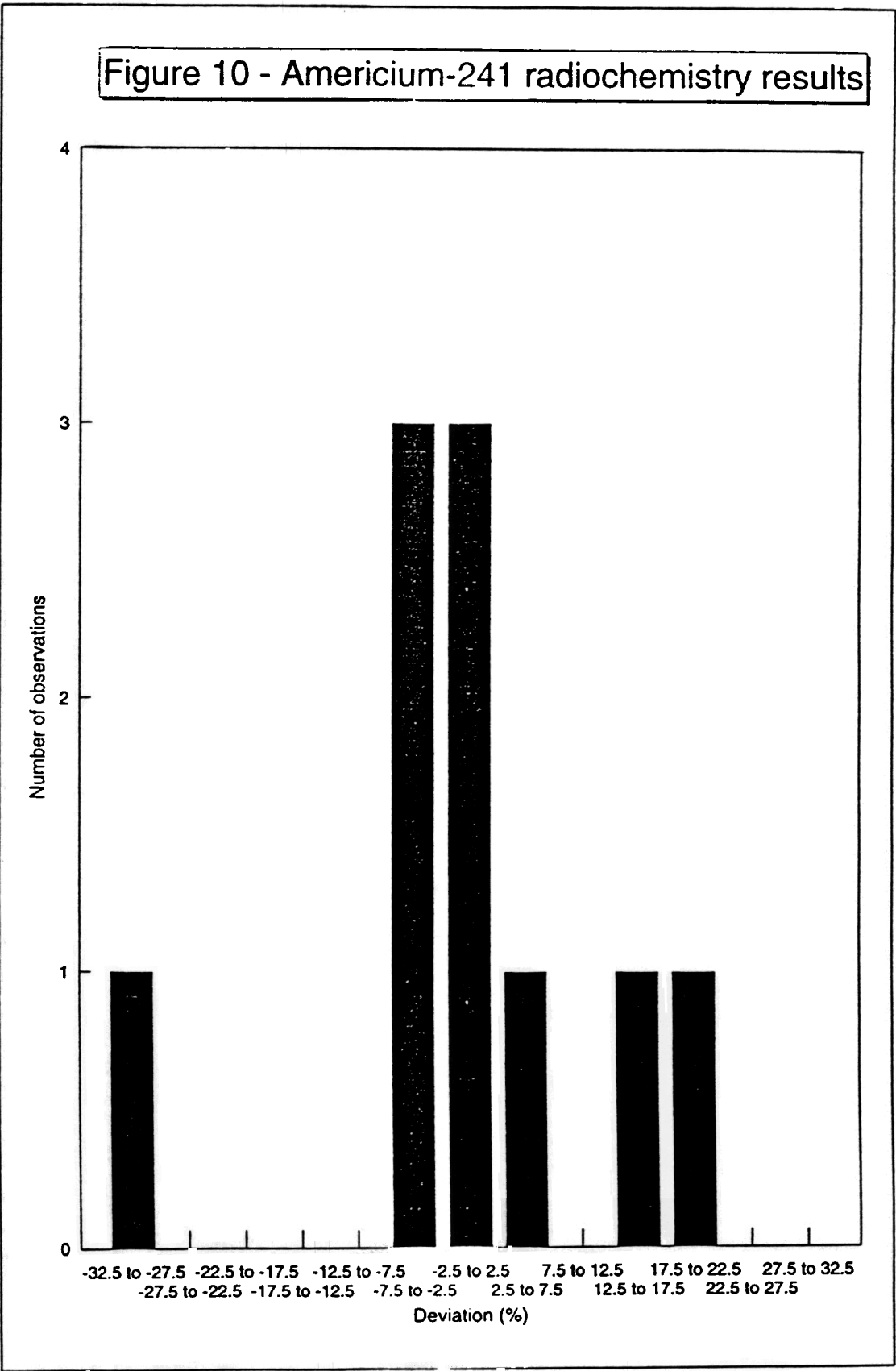


Figure 11 – Reported Tritium results

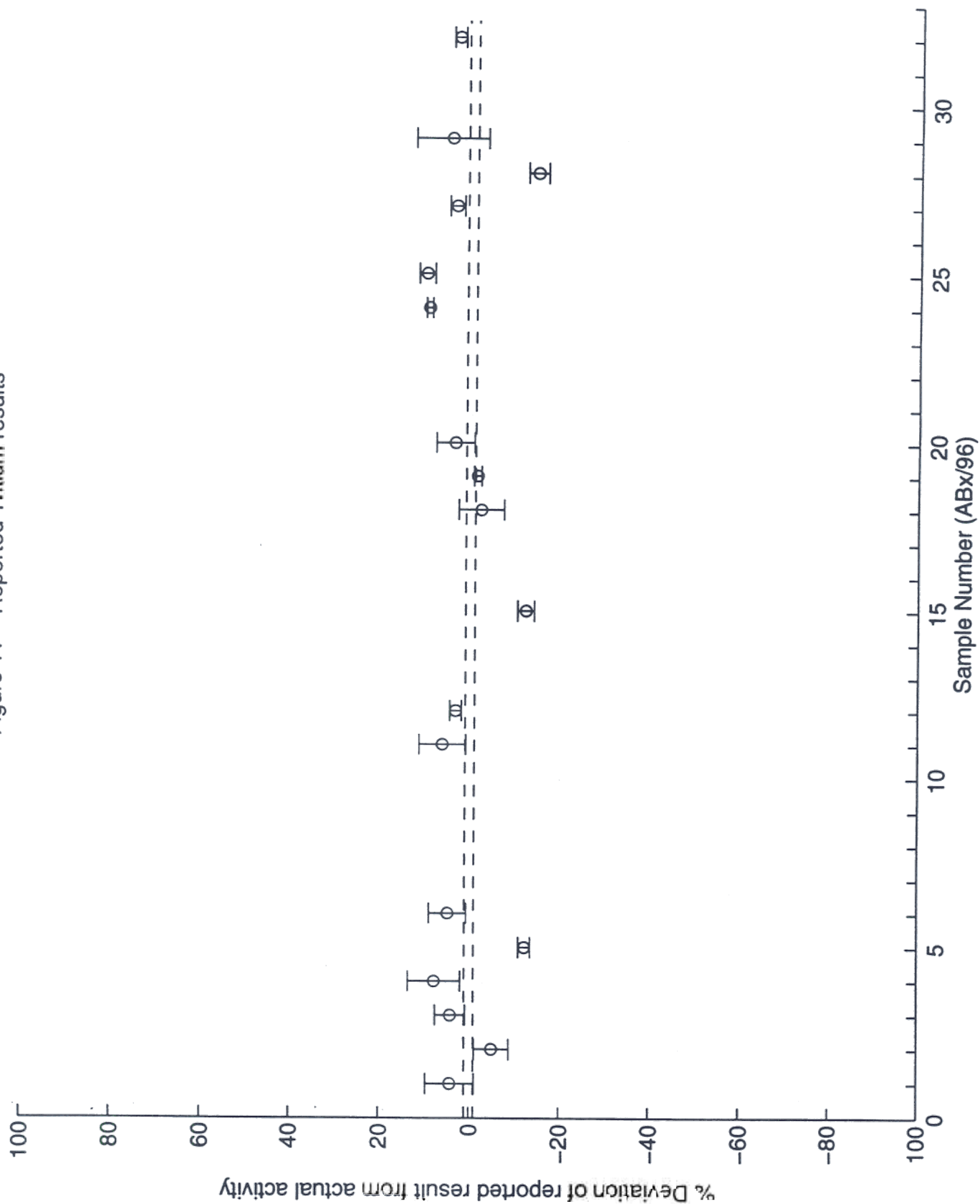


Figure 12 - Tritium results

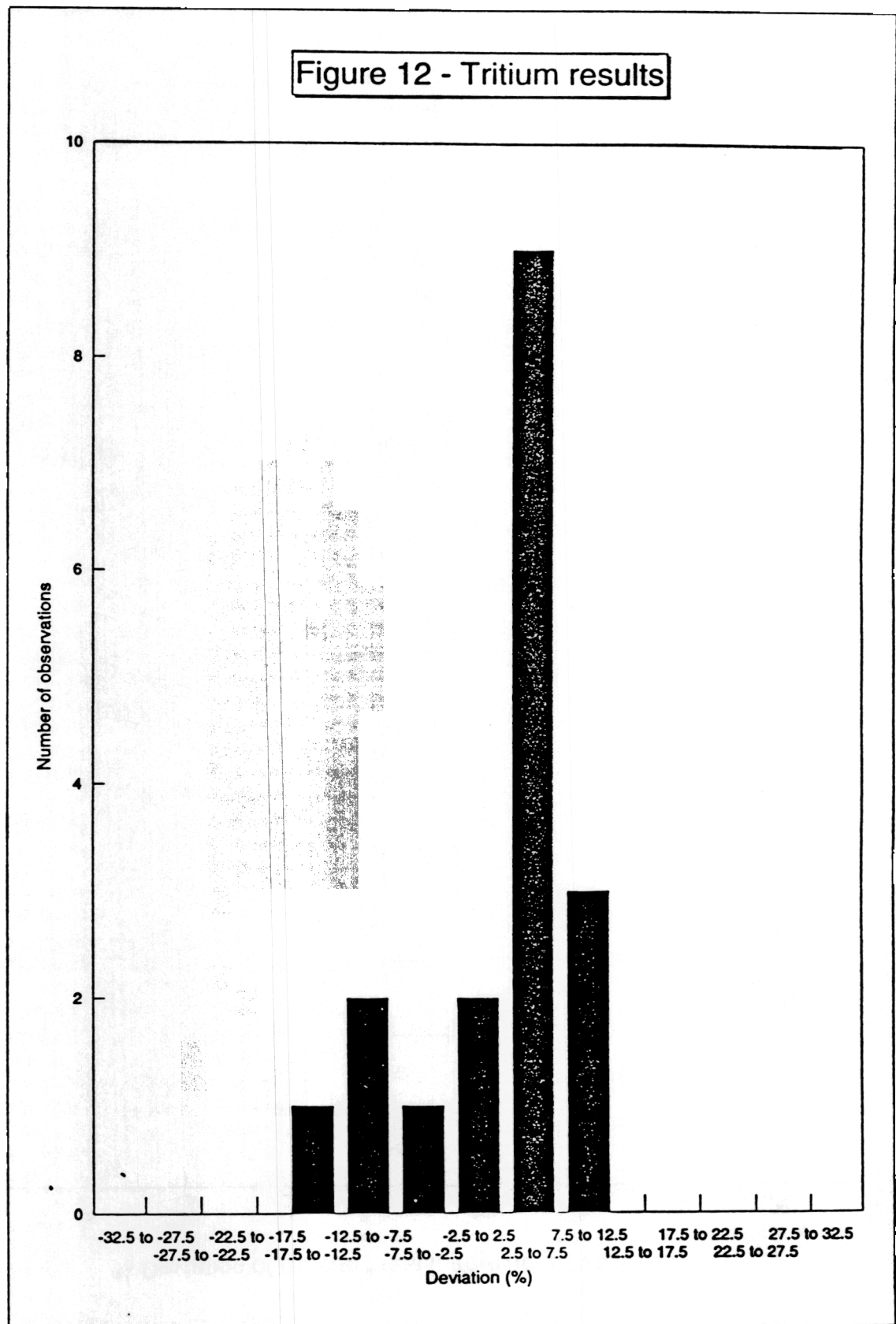
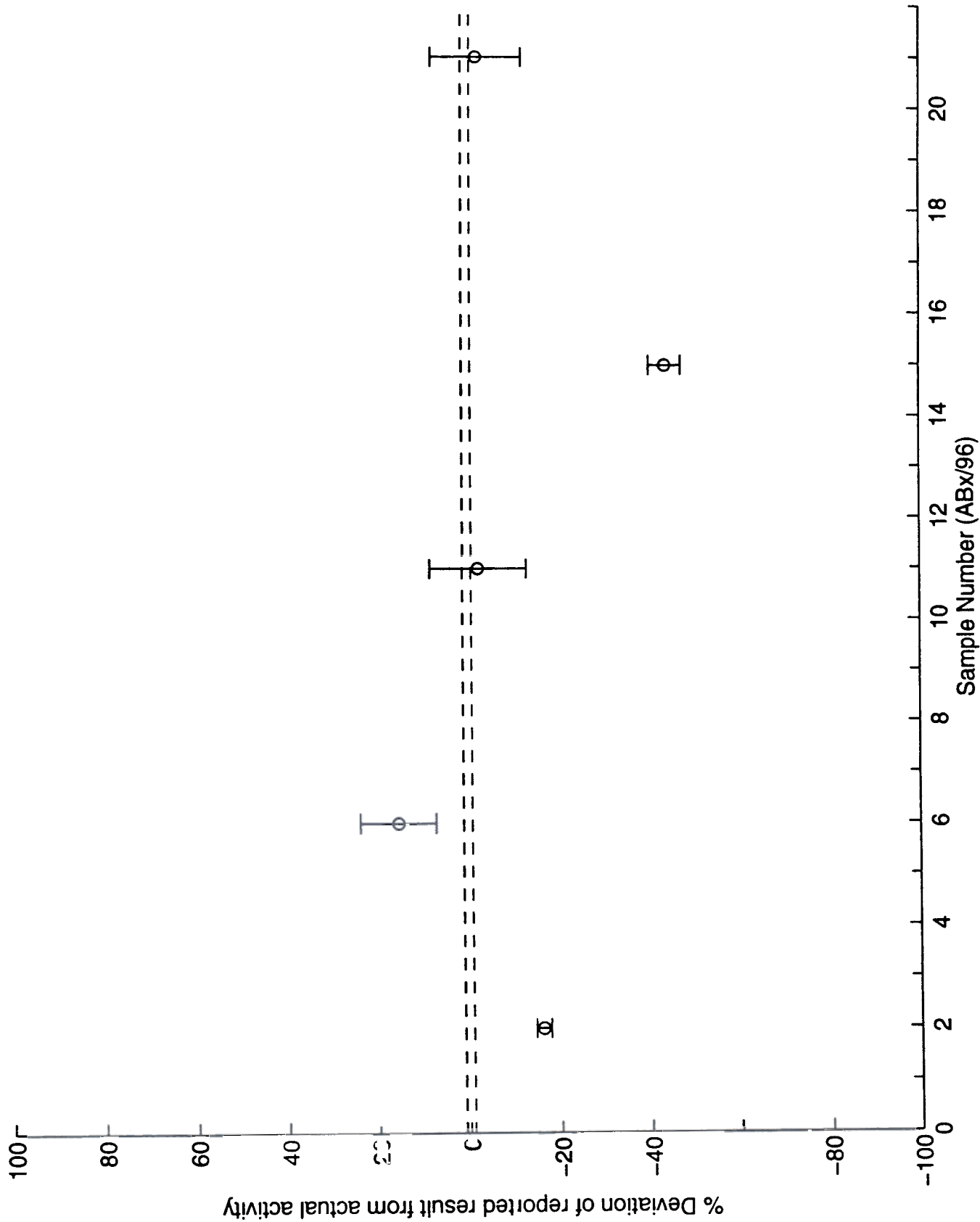
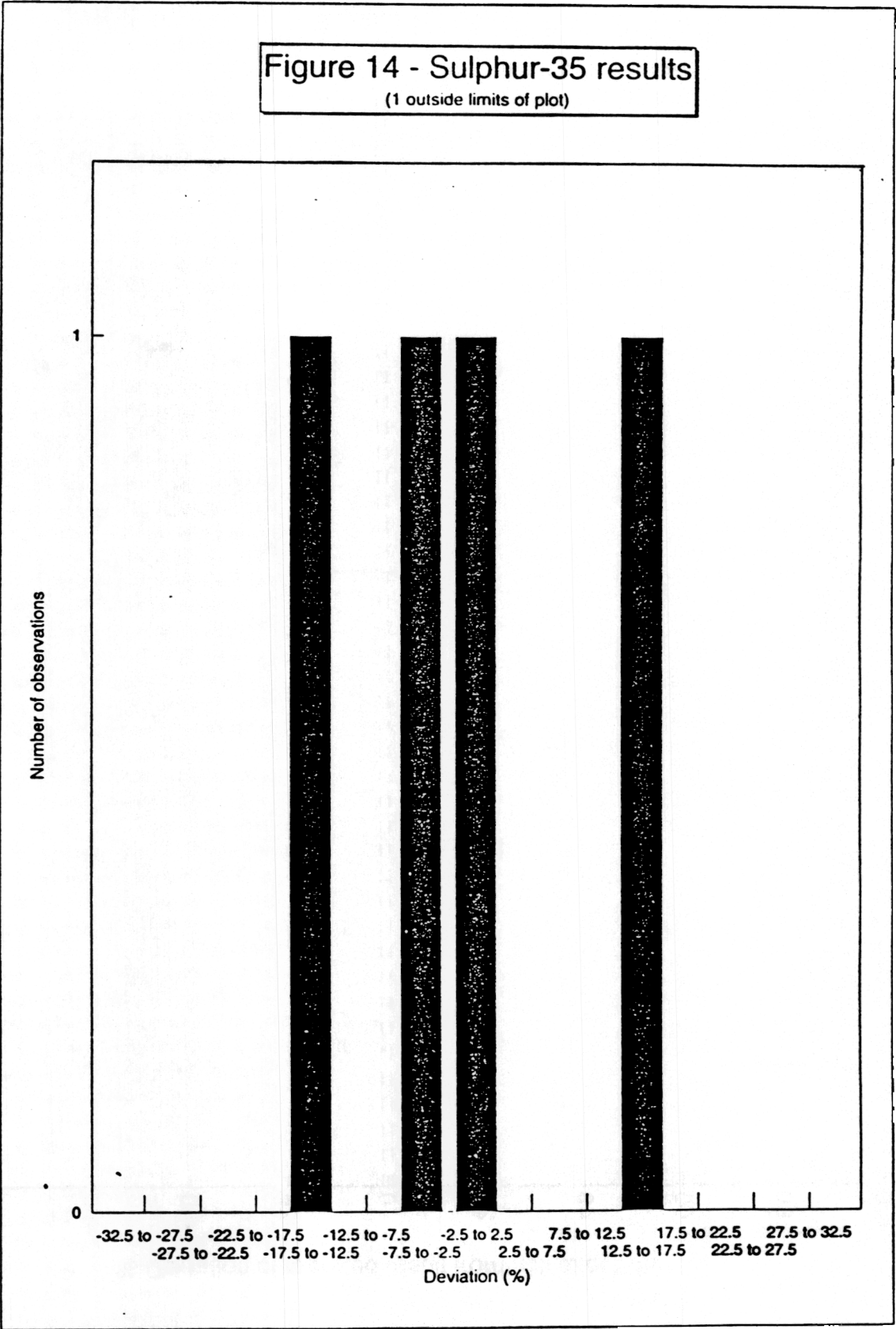


Figure 13 – Reported S-35 results





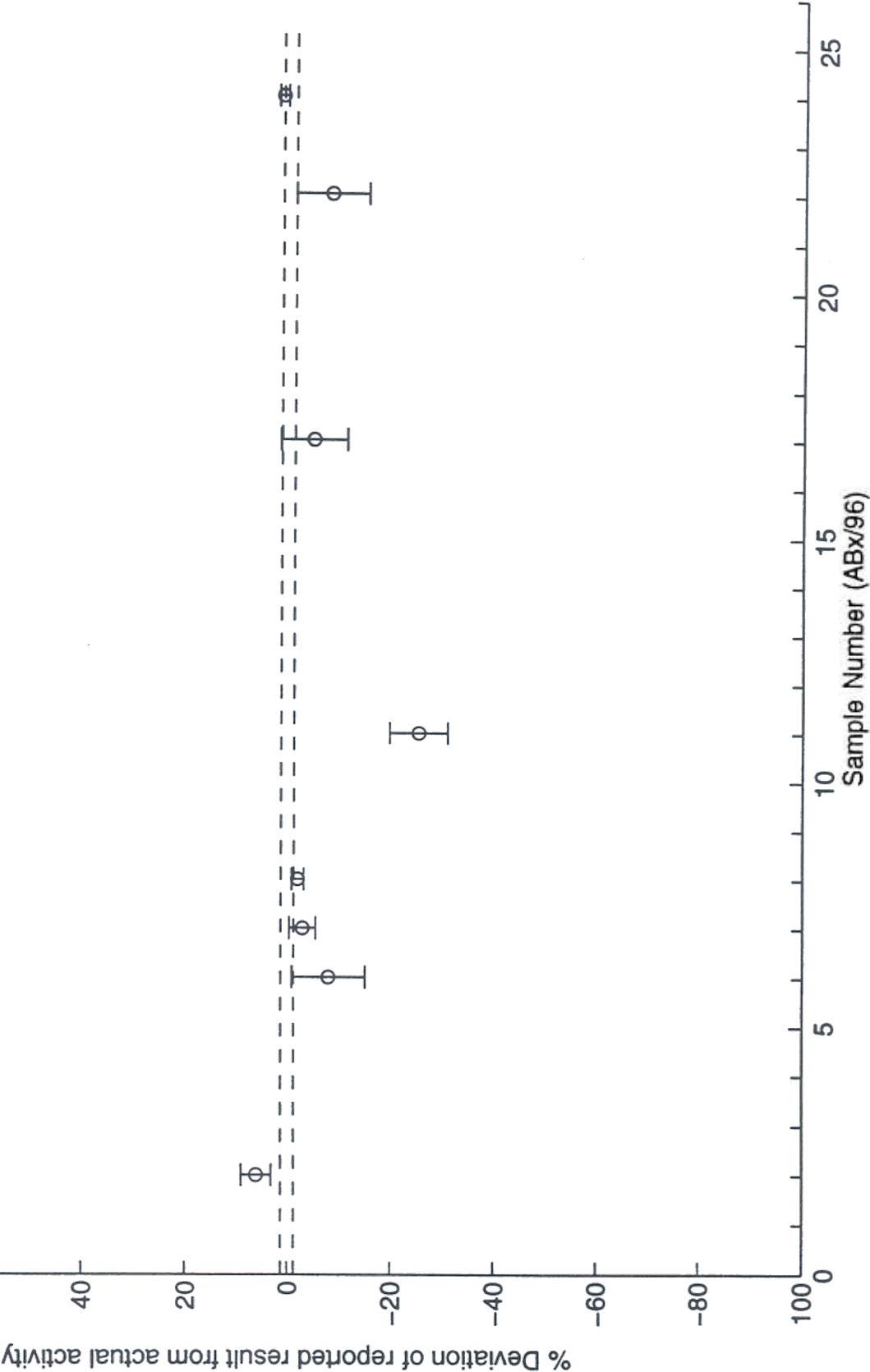


Figure 15 – Reported Sr-90 results

Figure 16 - Strontium-90 results
(1 outside limits of plot)

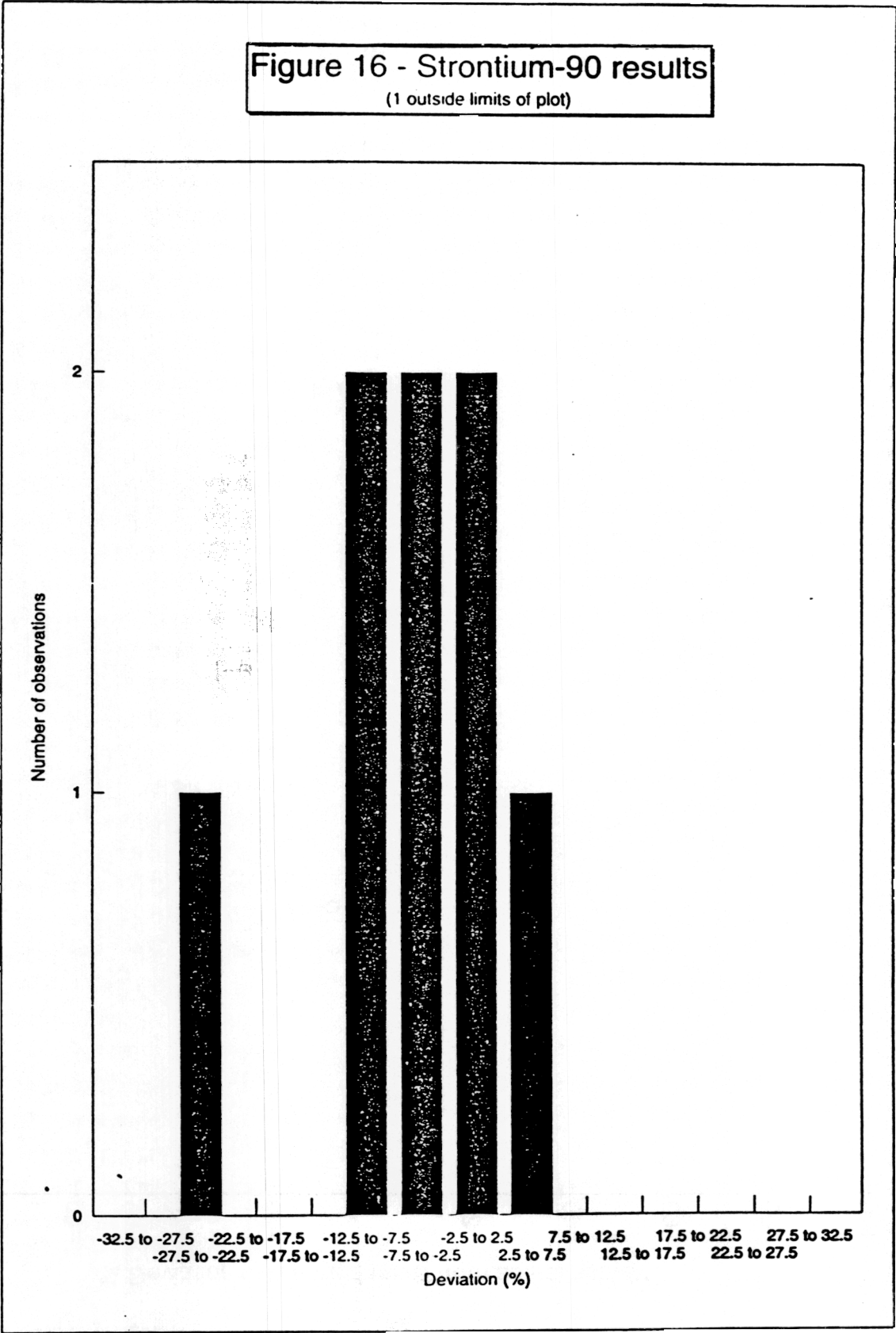


Figure 17 -- Reported Tc-99 results

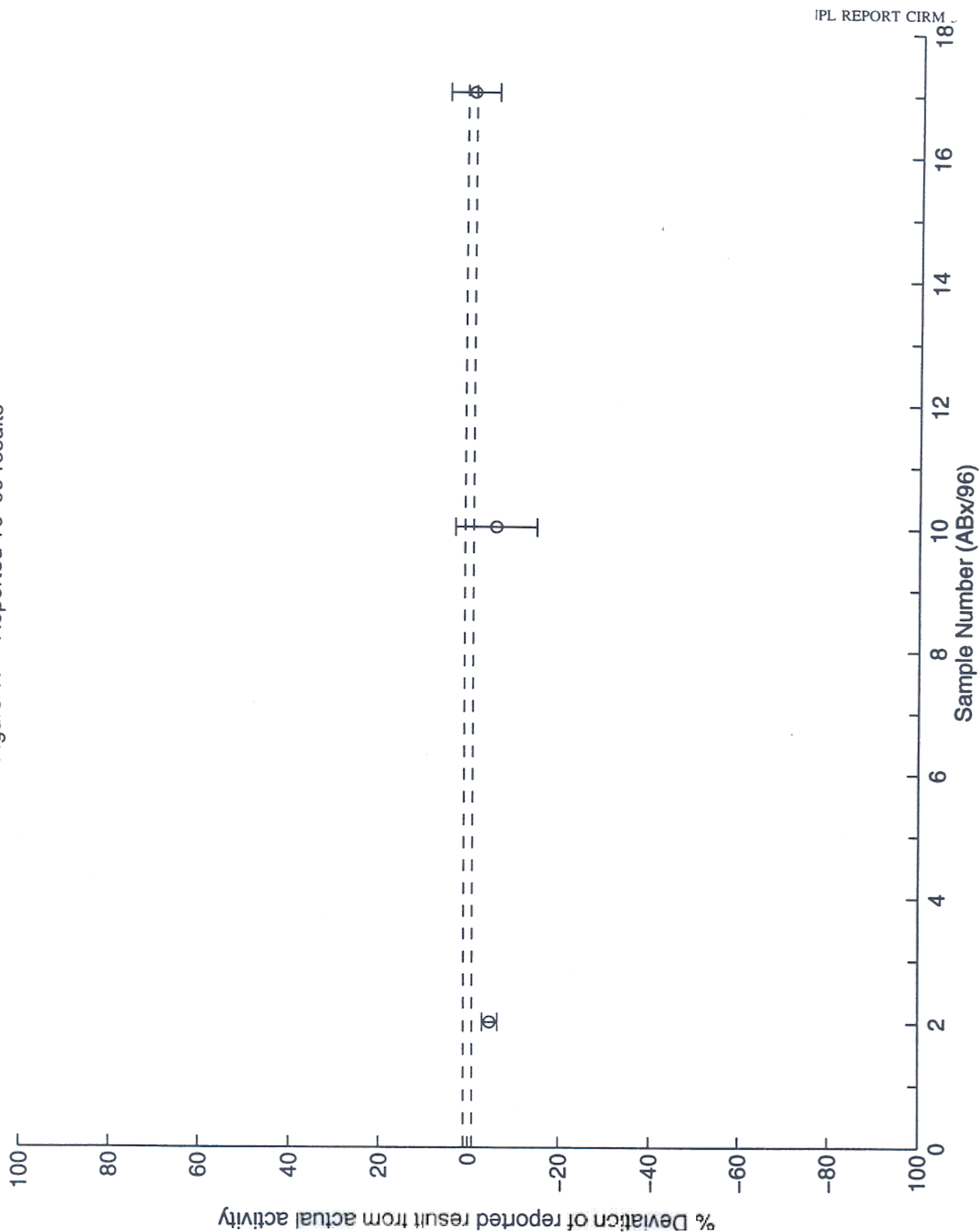


Figure 18 - Technetium-99 results

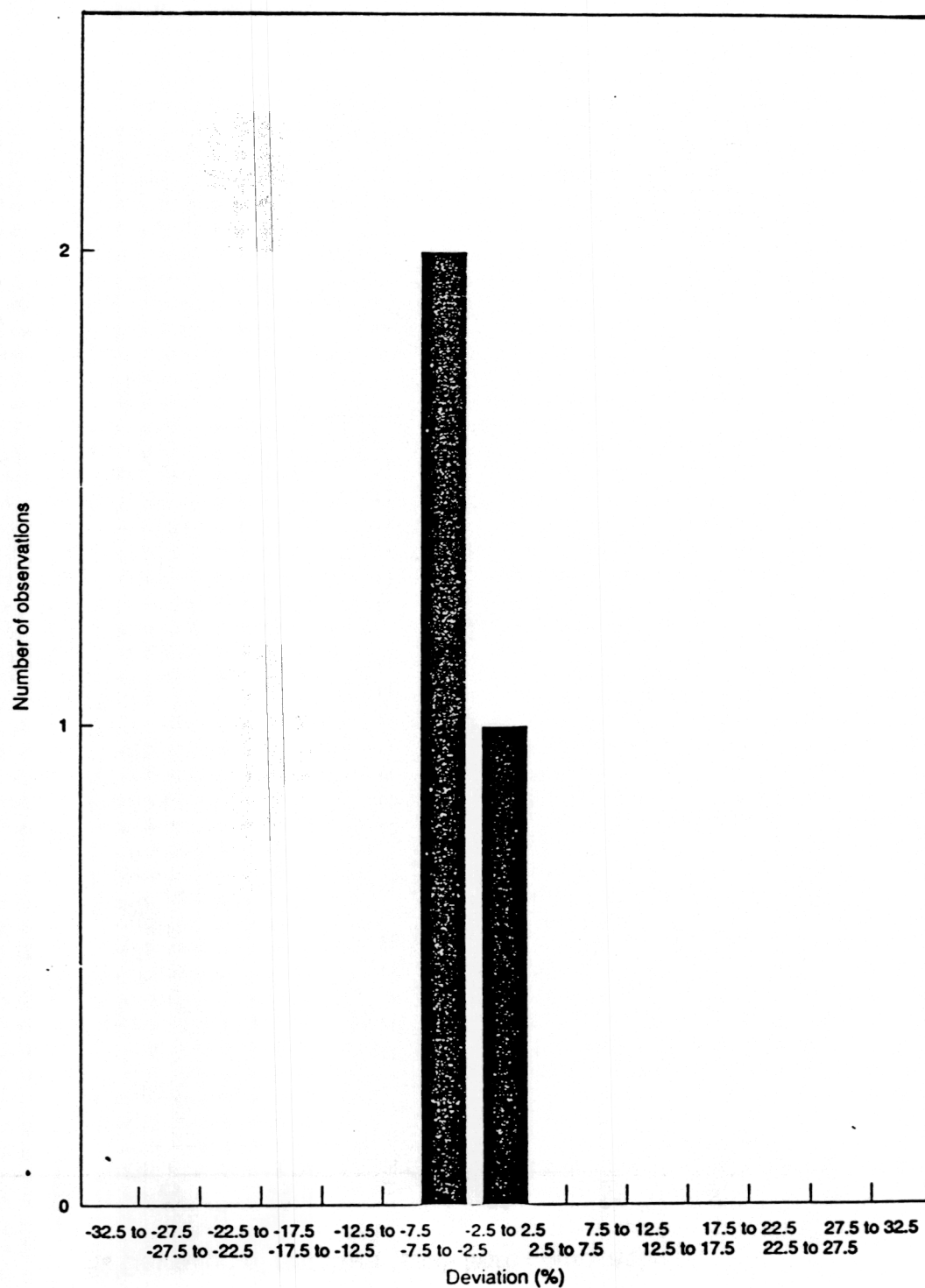
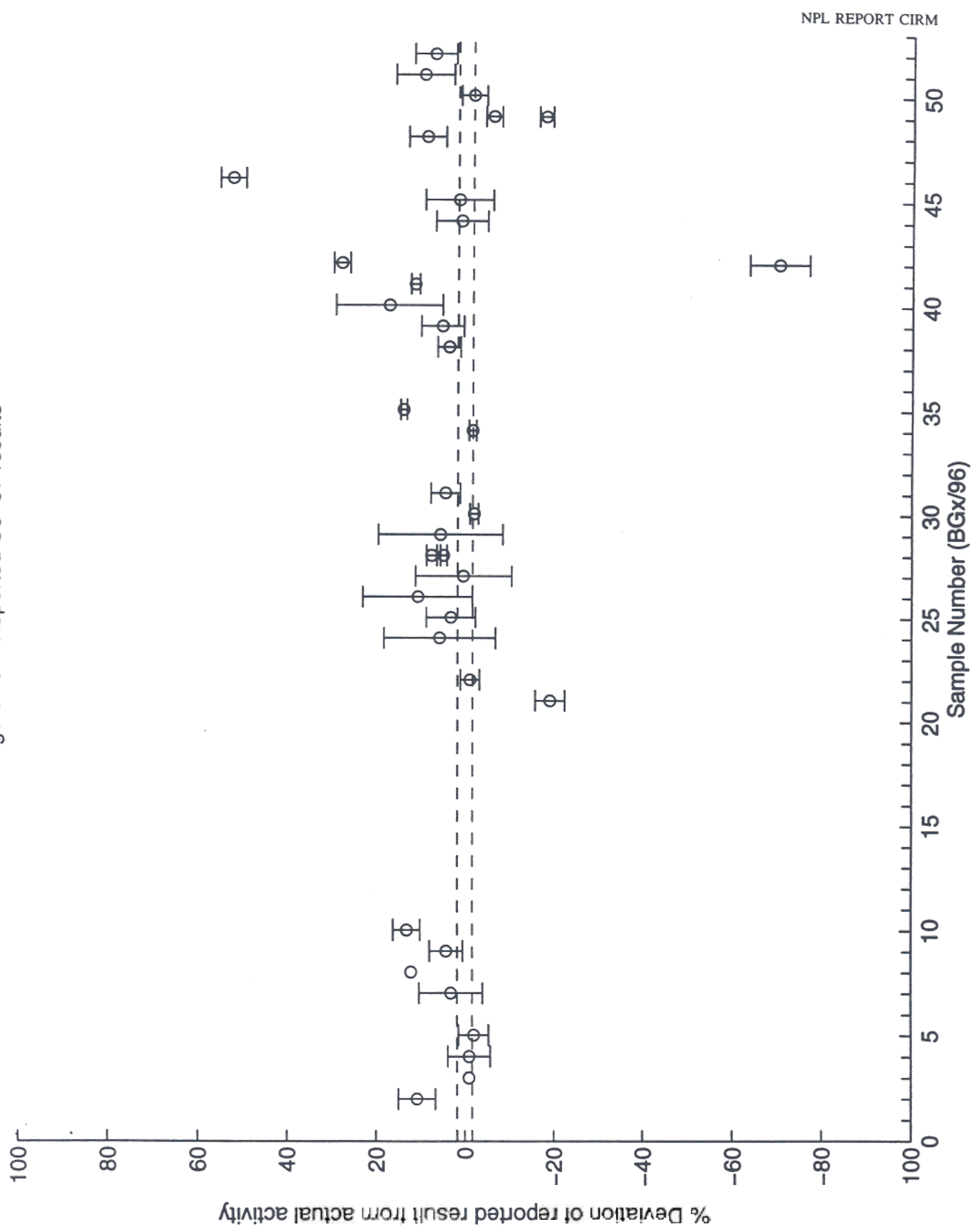


Figure 19 – Reported Co-57 results



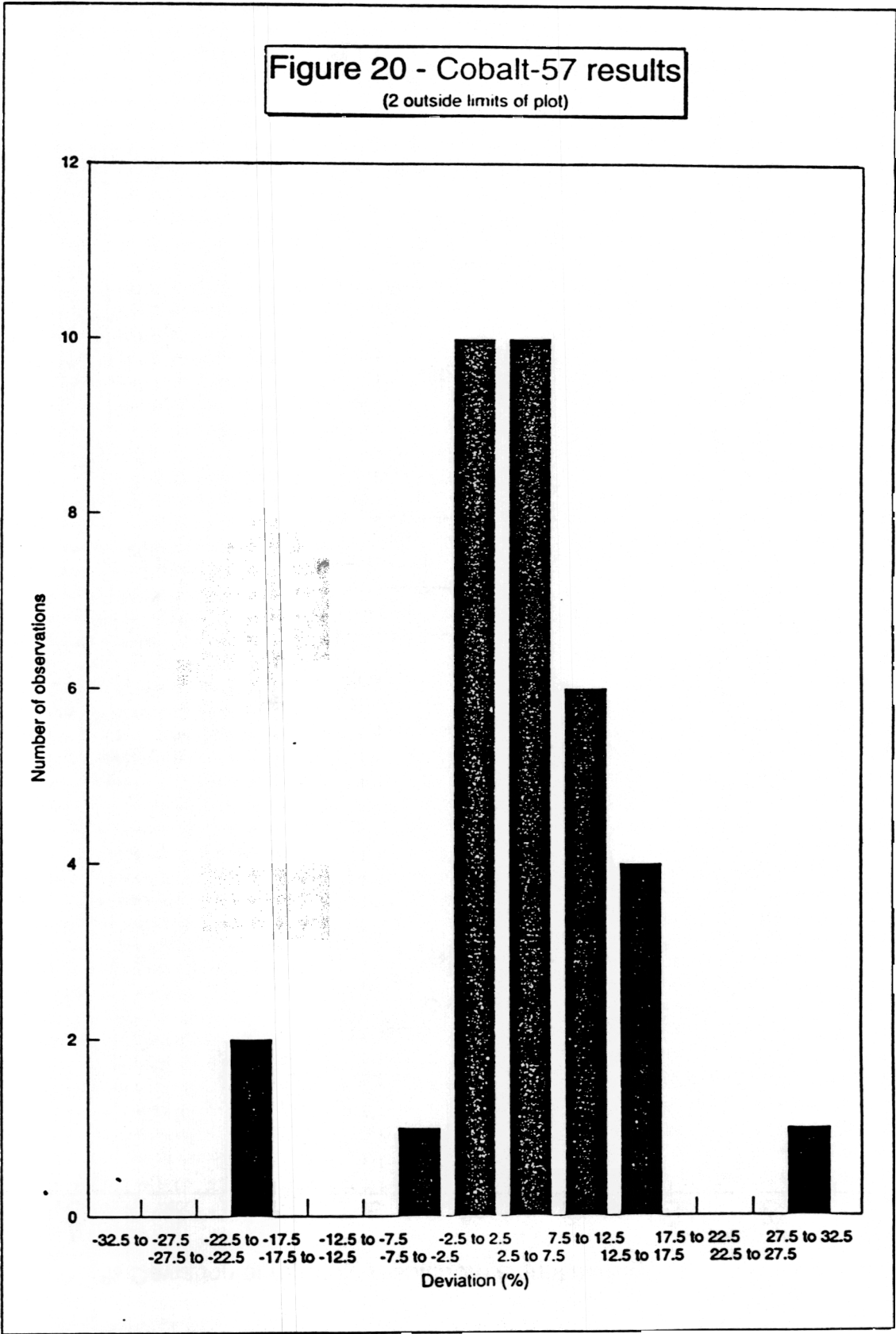
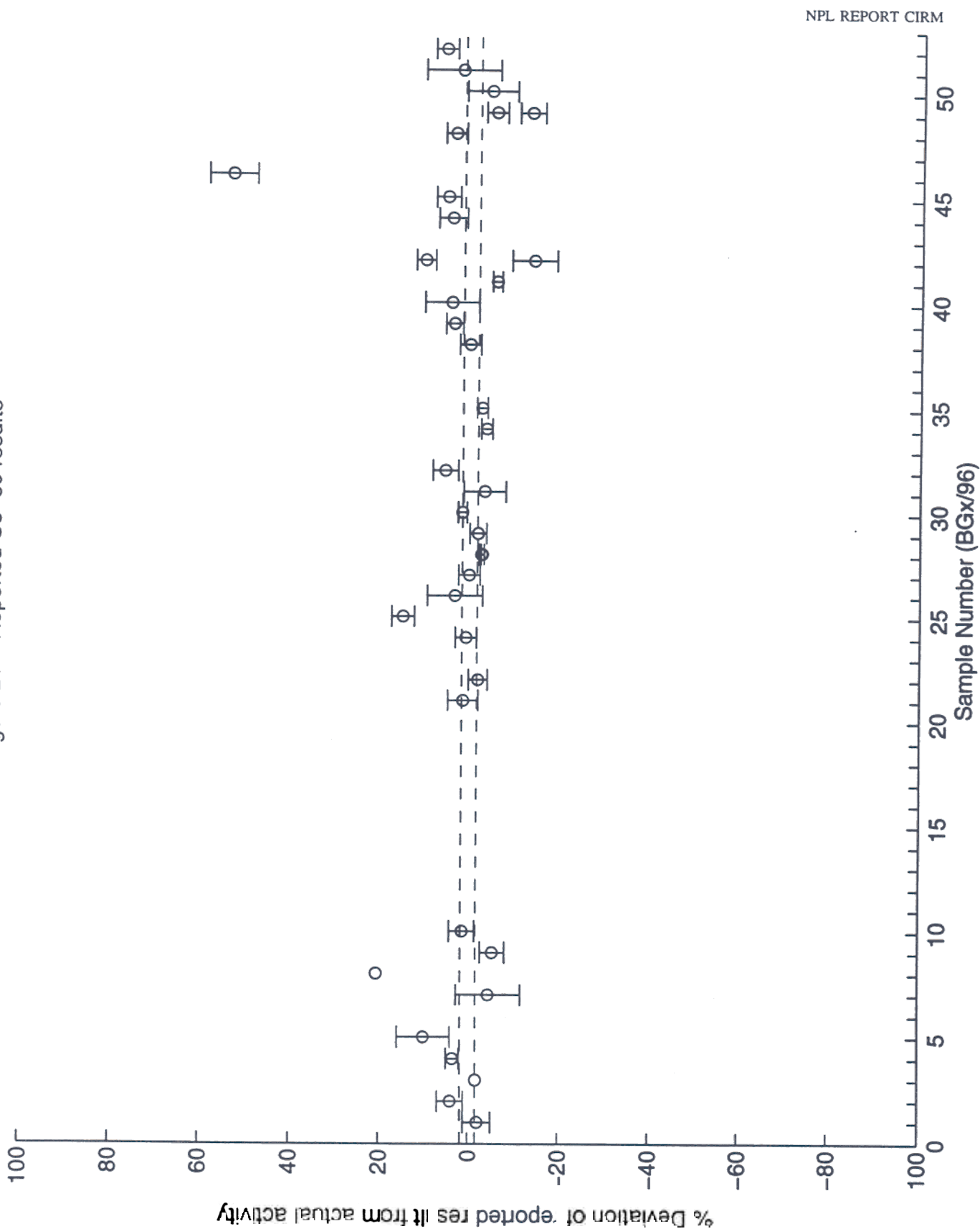


Figure 21 – Reported Co-60 results



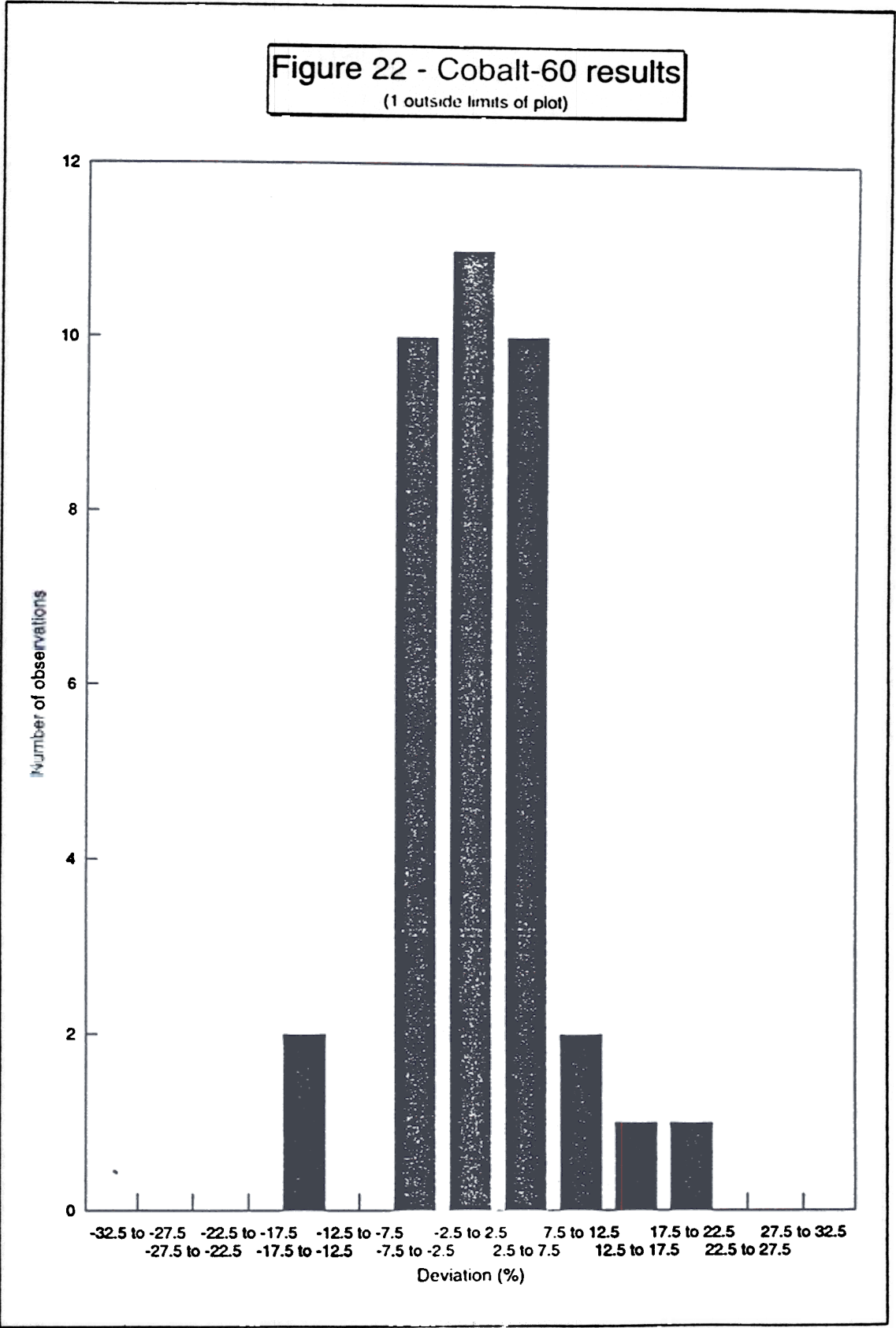
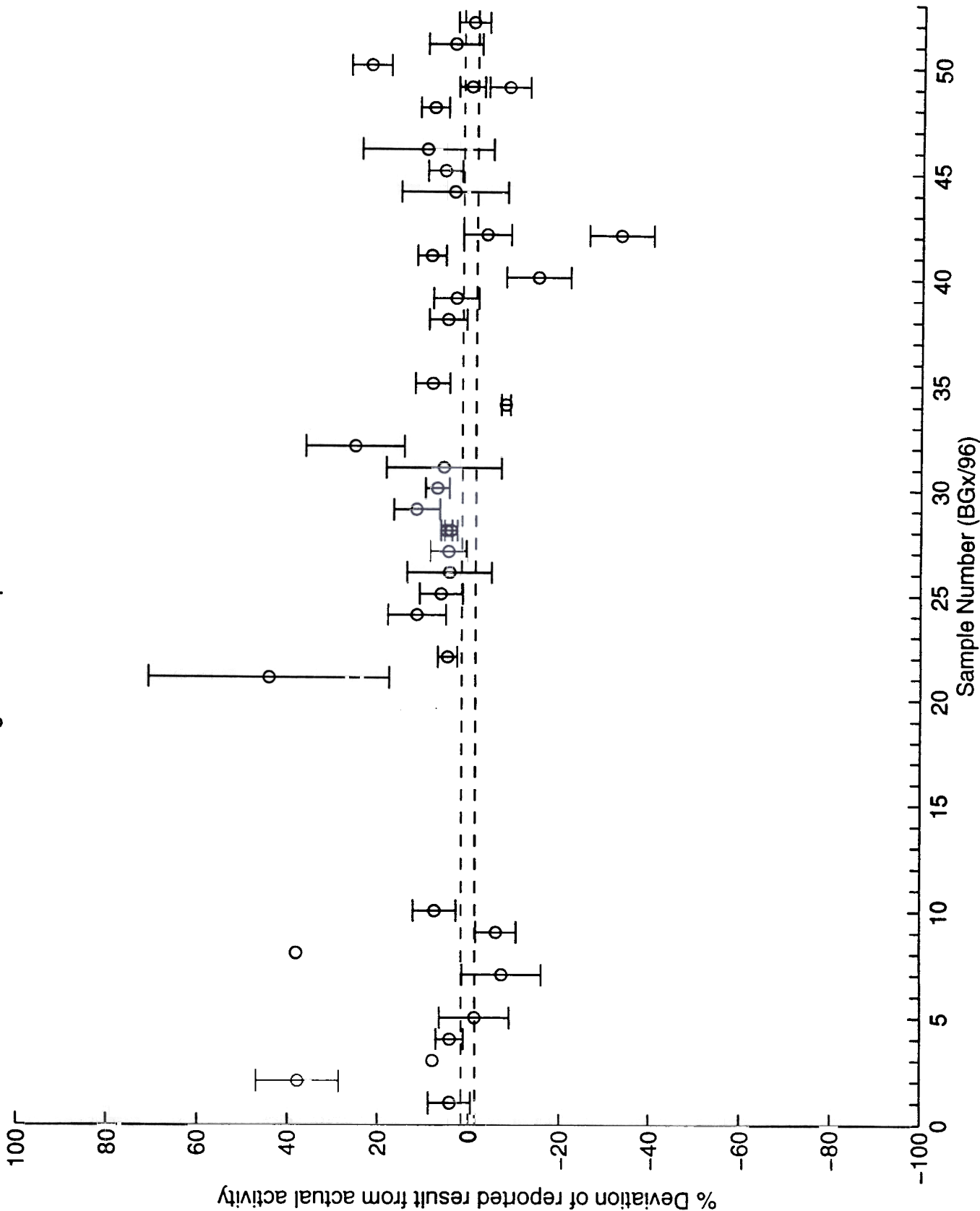


Figure 23 – Reported Sb-125 results



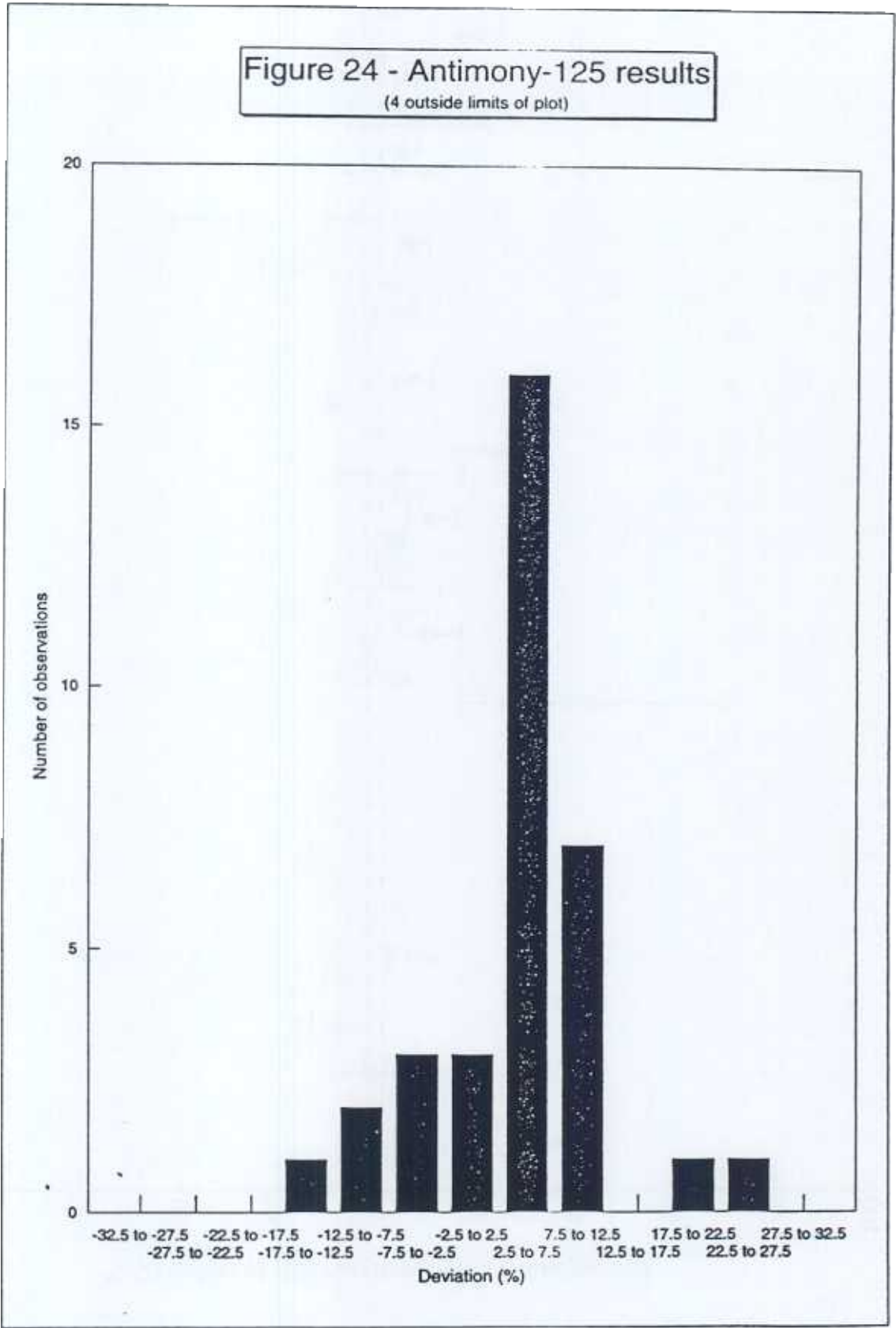


Figure 25 -- Reported Cs-134 results

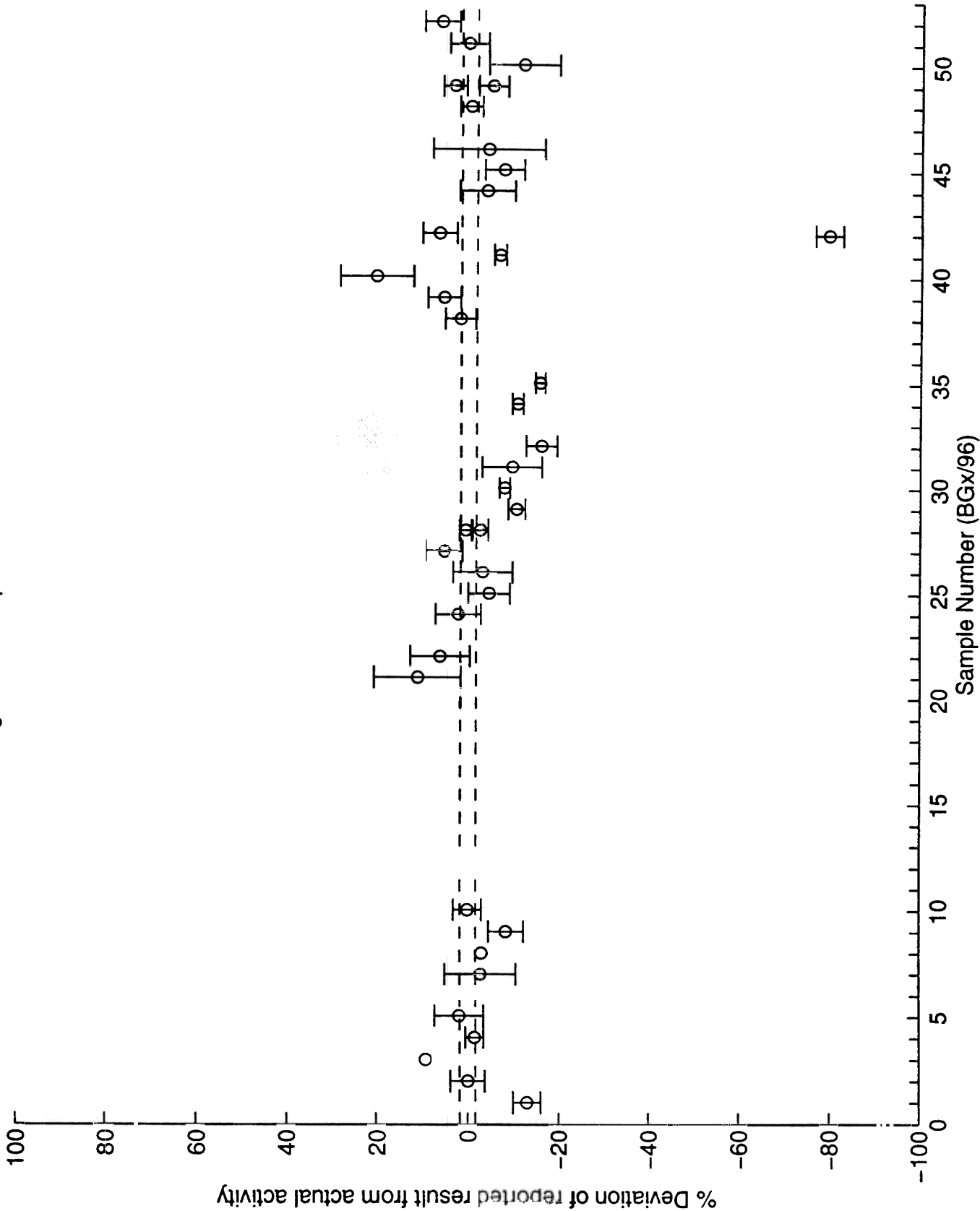


Figure 26 - Caesium-134 results
(1 outside limits of plot)

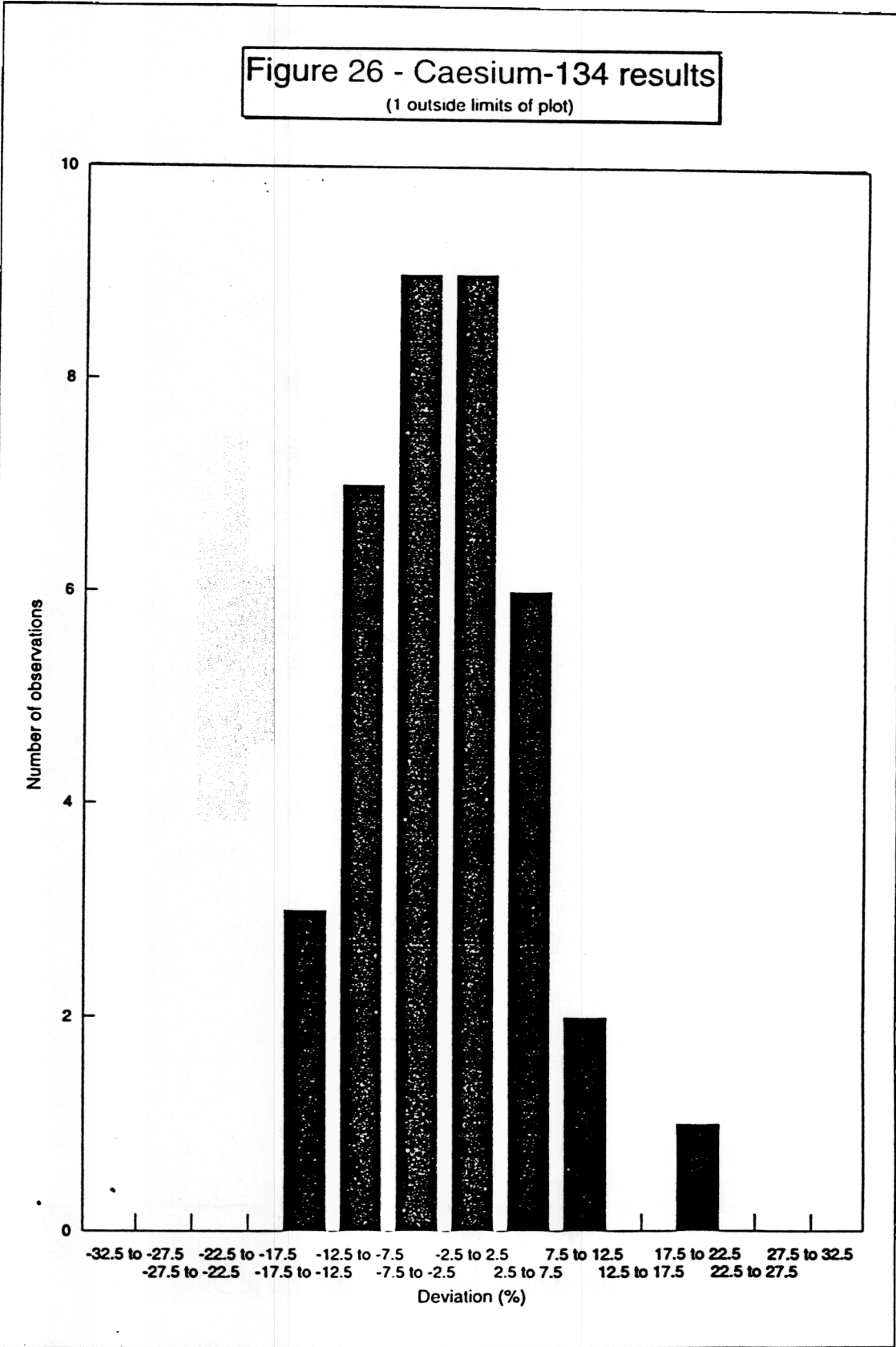


Figure 27 – Reported Cs-137 results

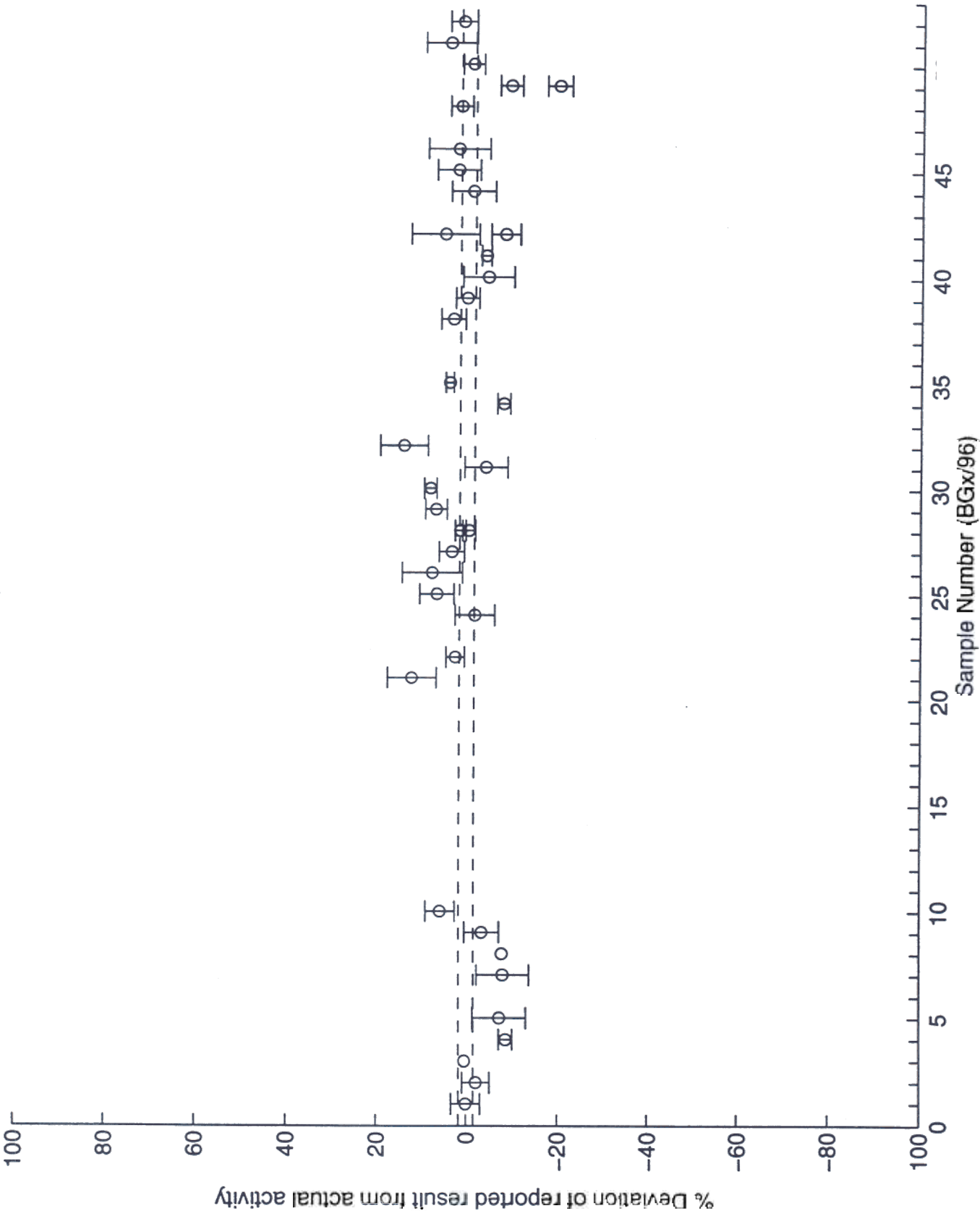


Figure 28 - Caesium-137 results

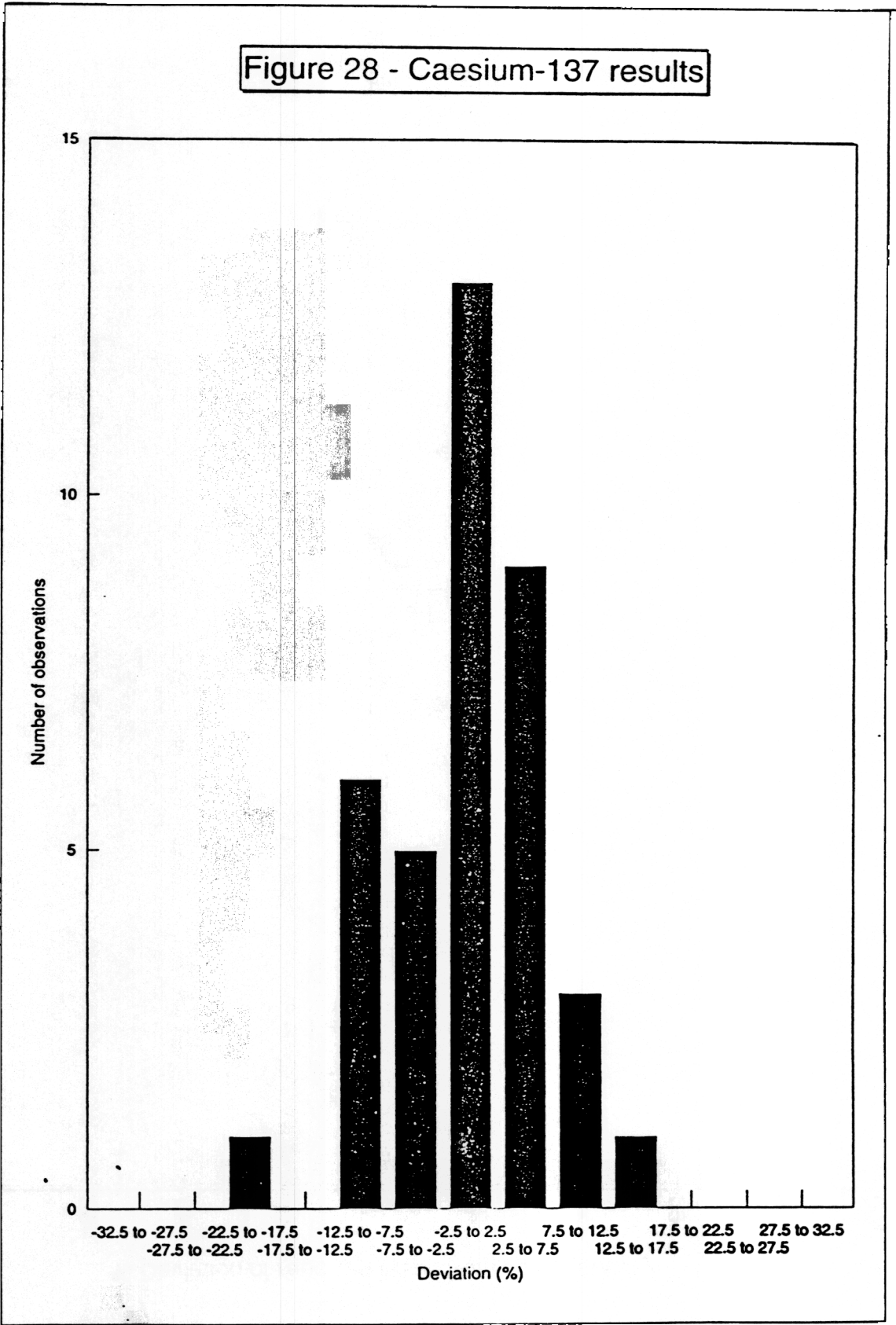


Figure 29 Reported Eu-154 results

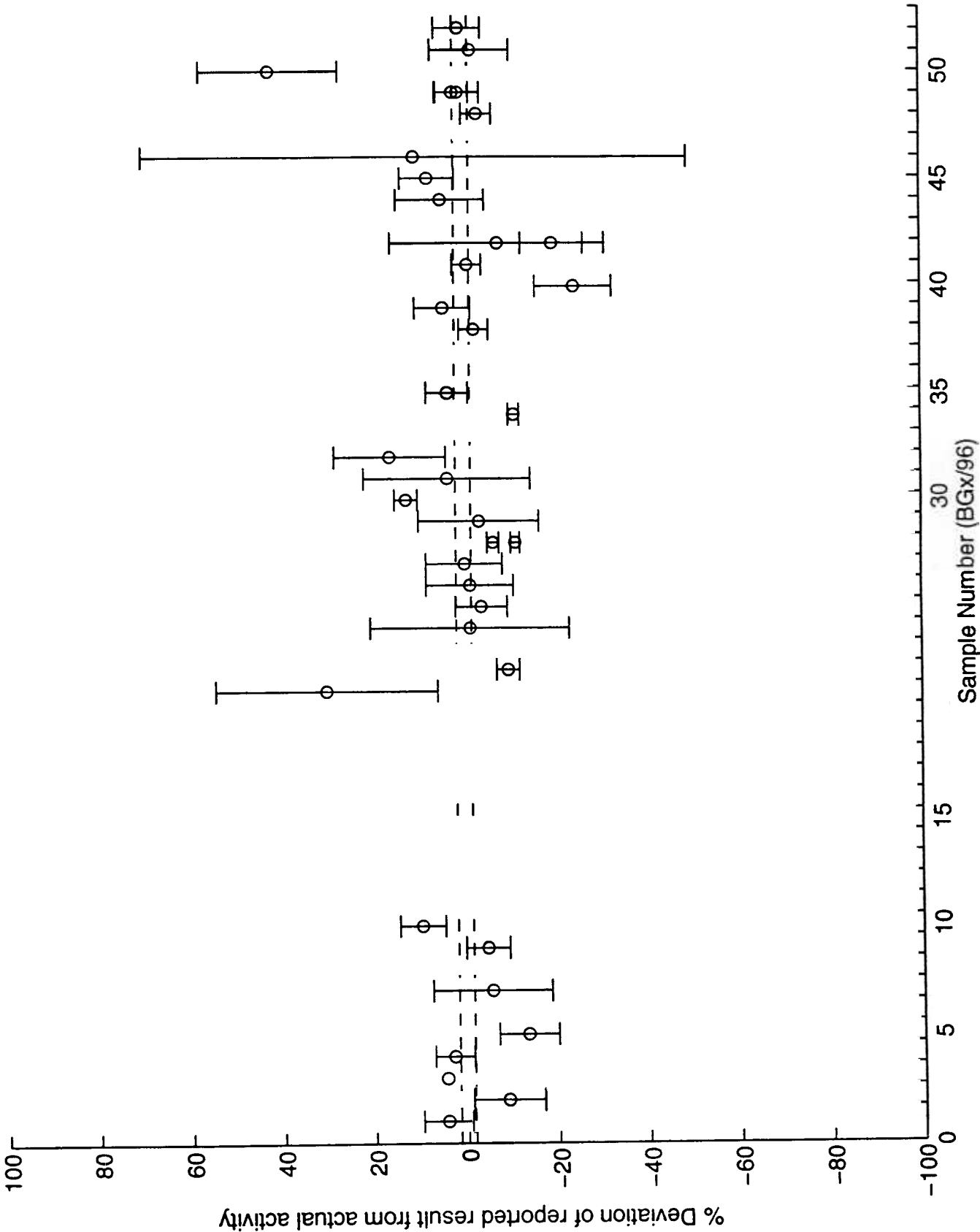


Figure 30 - Europium-154 results
(1 out side limits of plot)

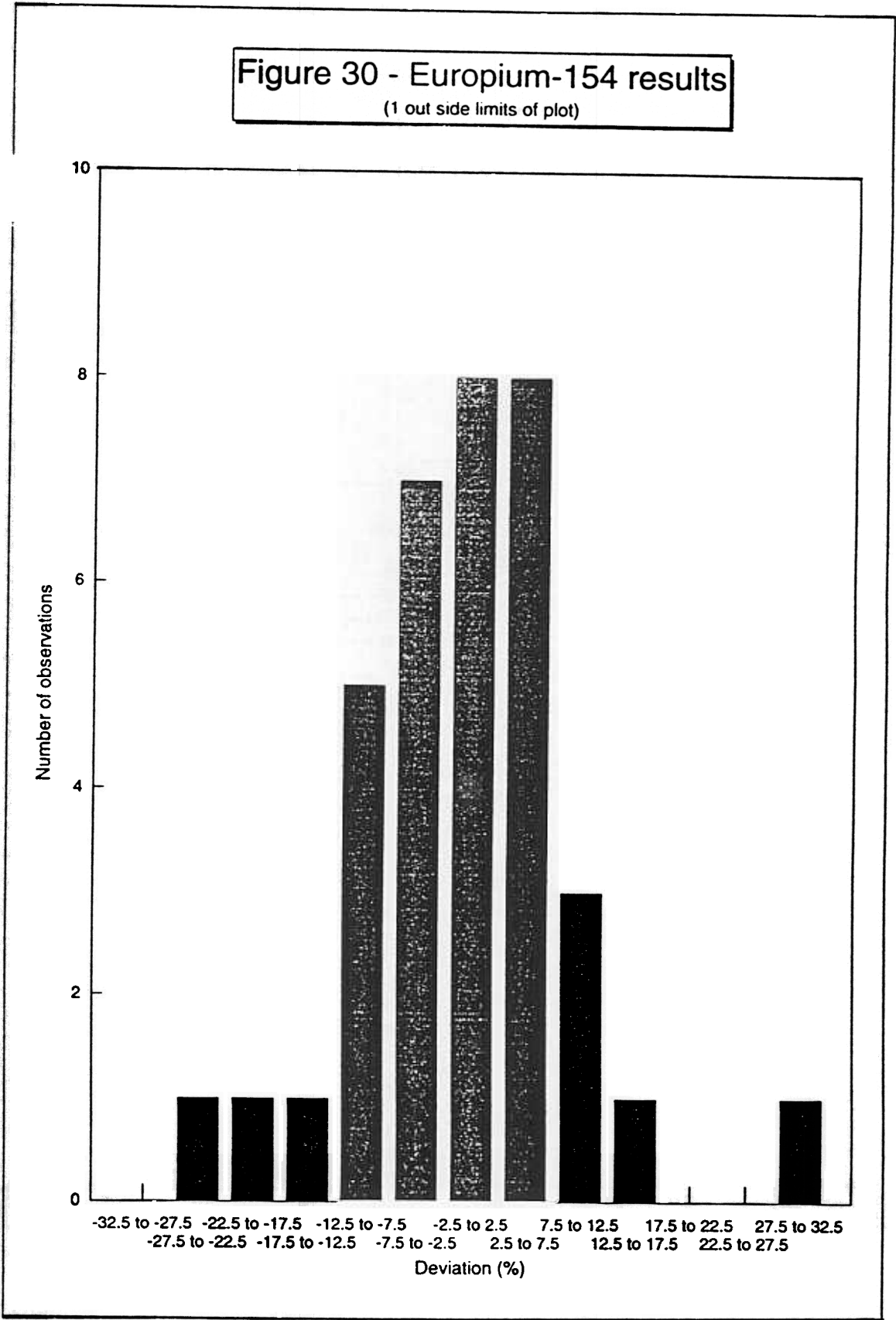


Figure 31 – Reported Eu-155 results

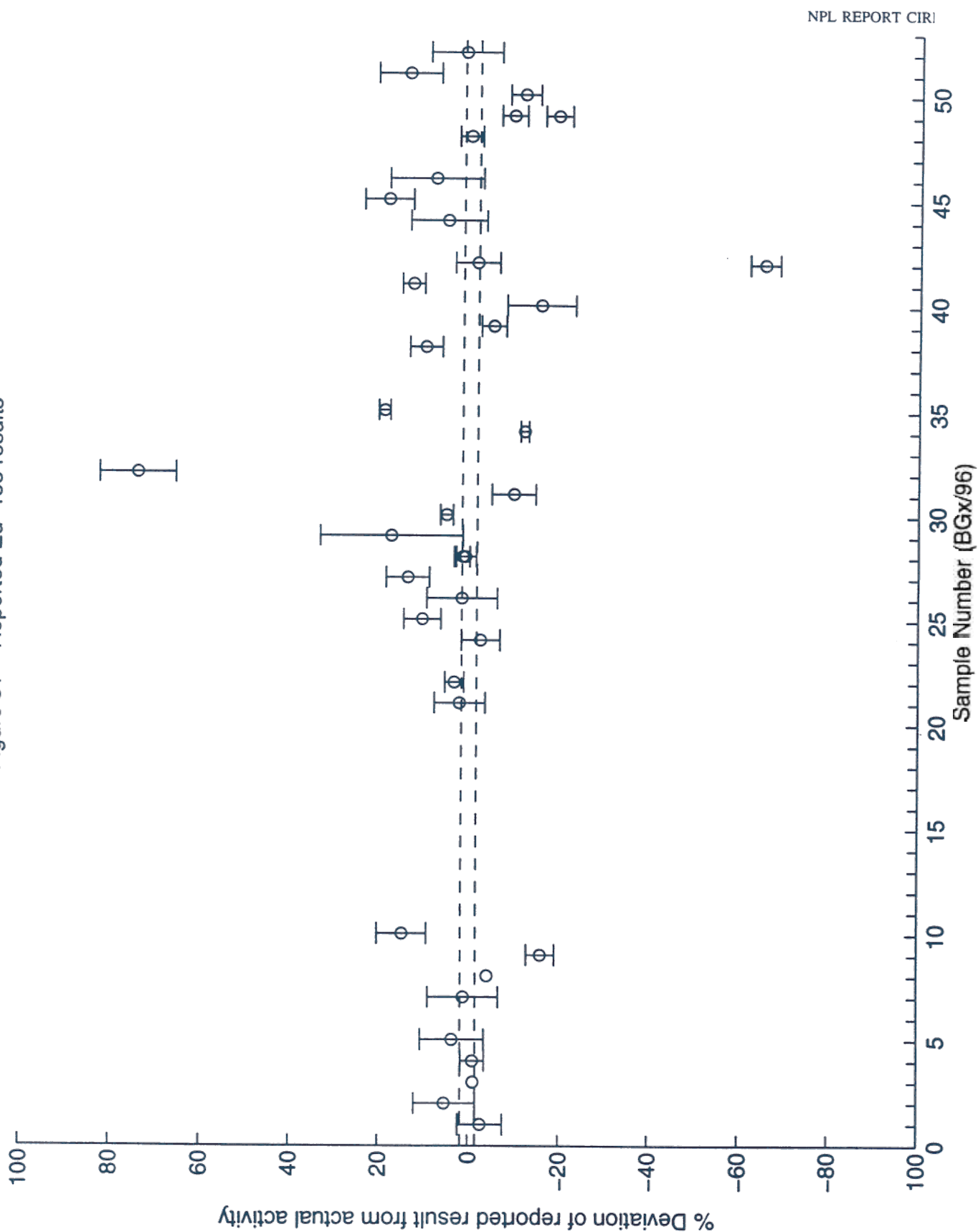


Figure 32 - Europium-155 results
(2 outside limits of plot)

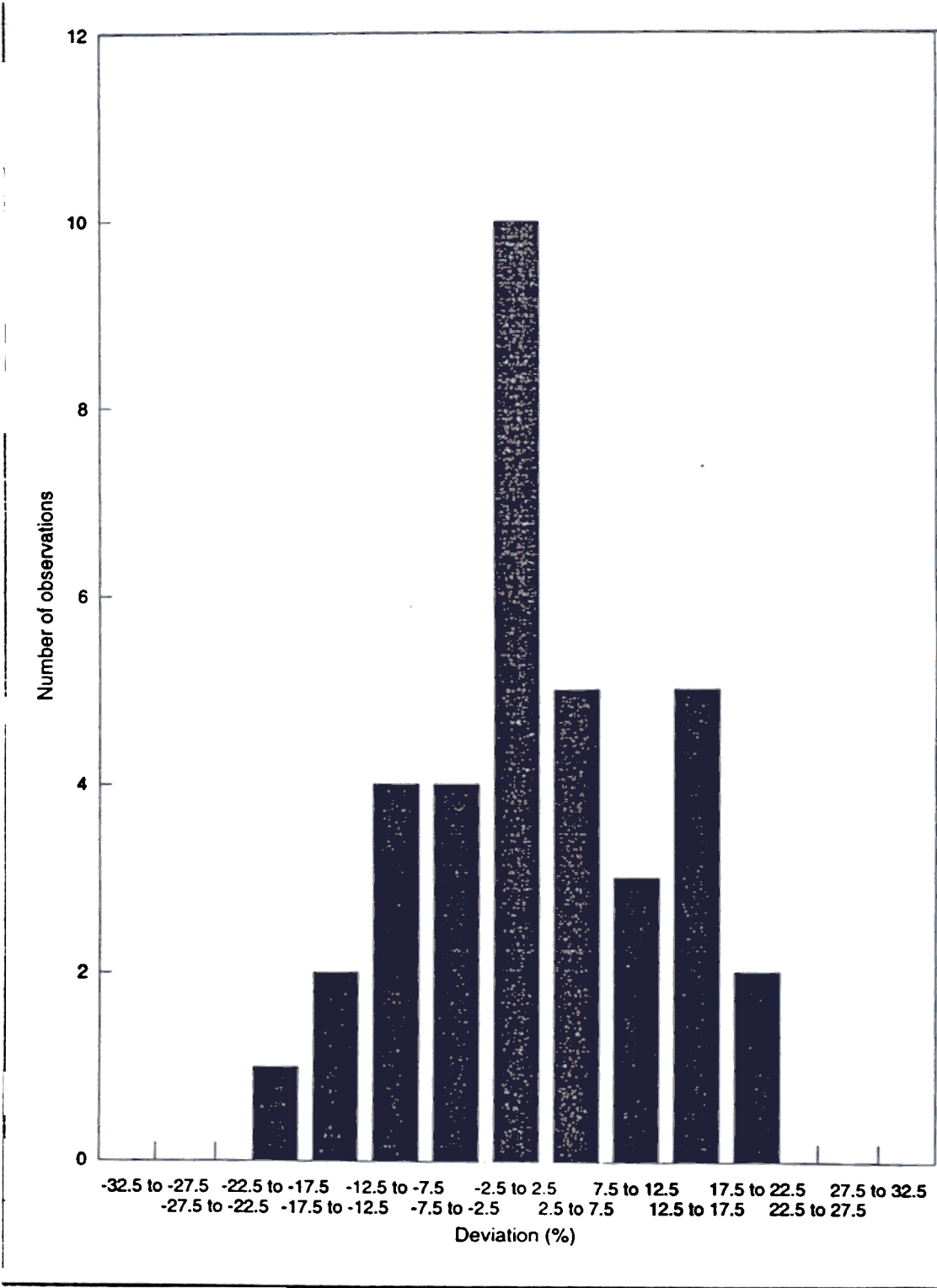
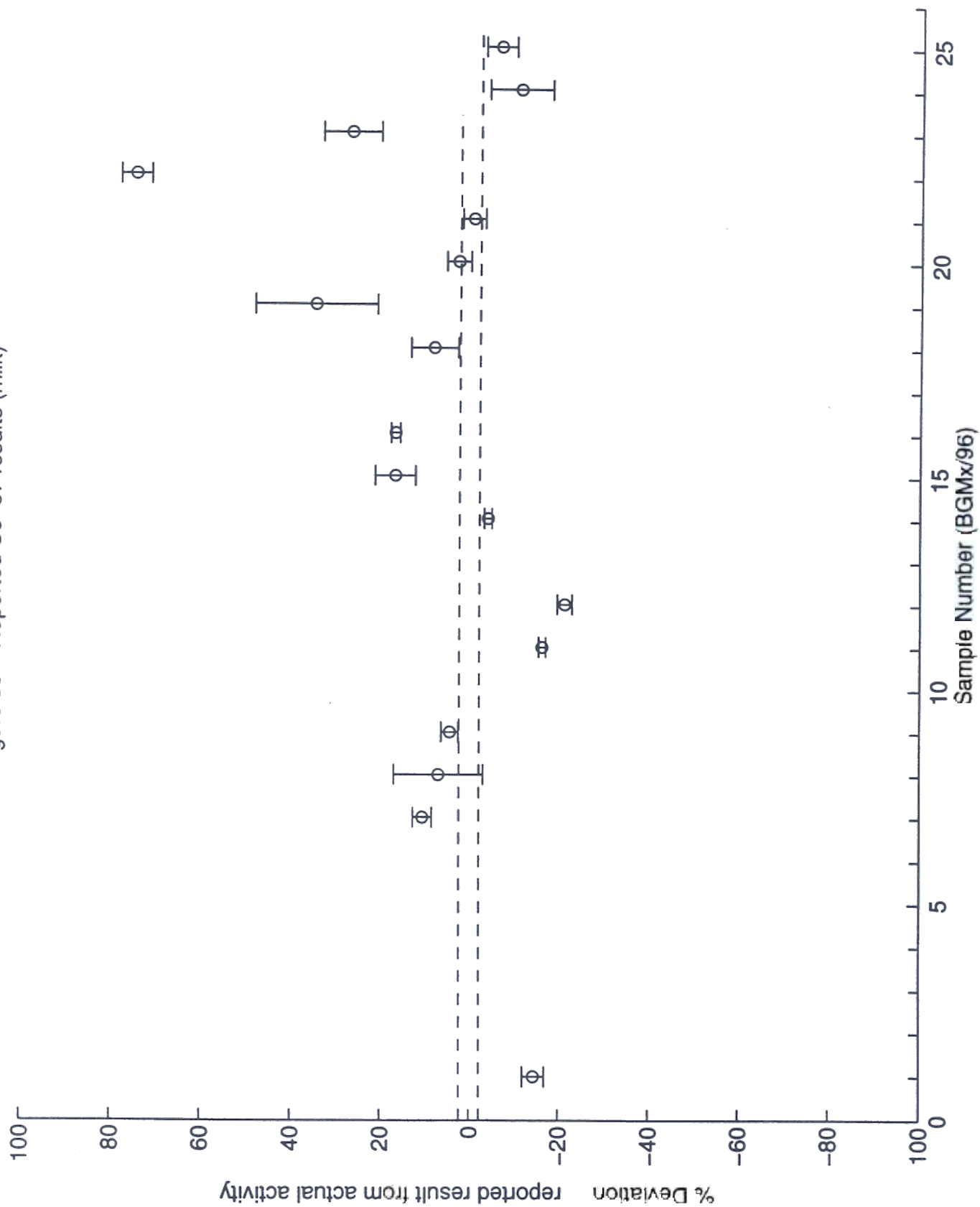


Figure 33 – Reported Co-57 results (milk)



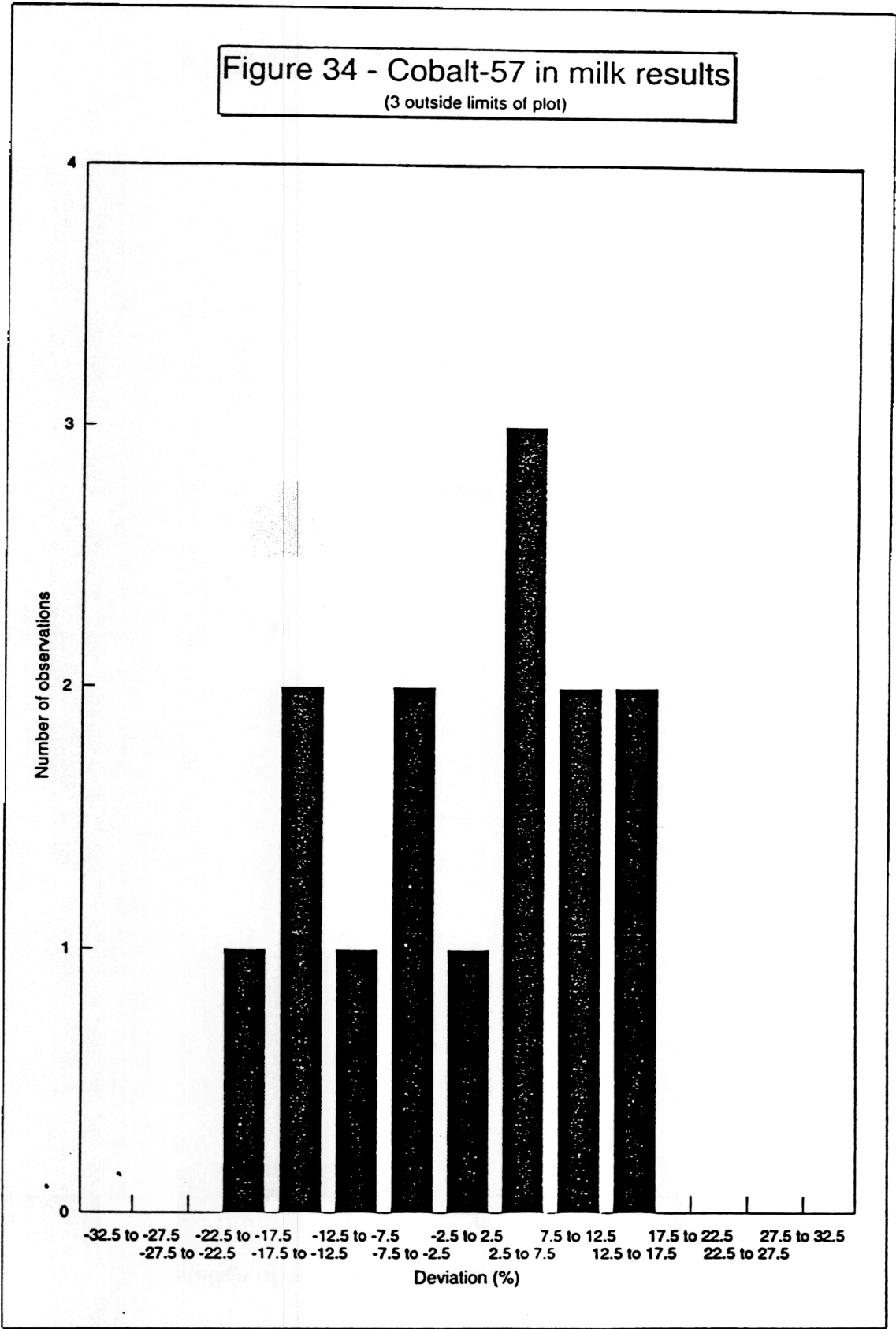


Figure 35 – Reported Co-60 results (milk)

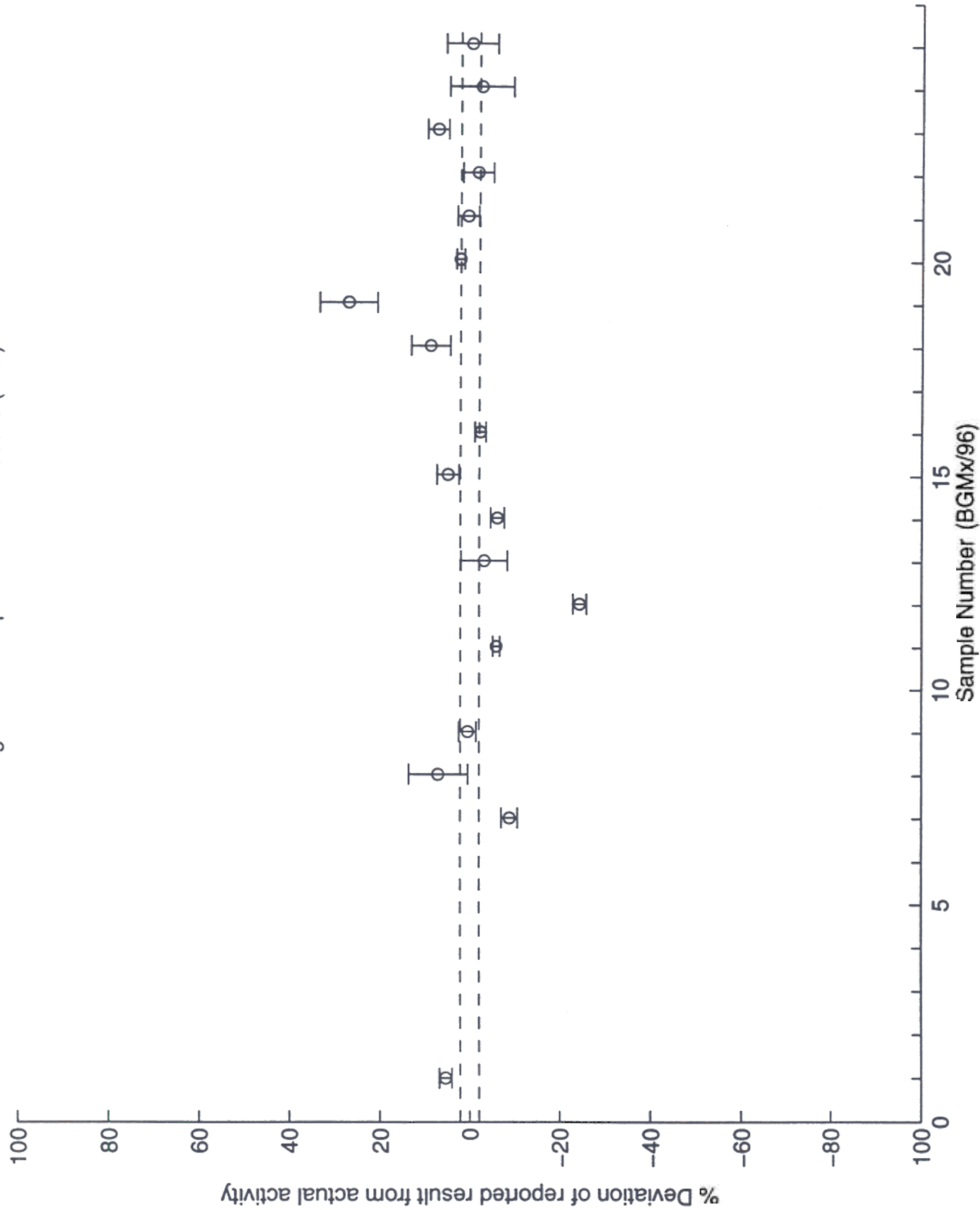
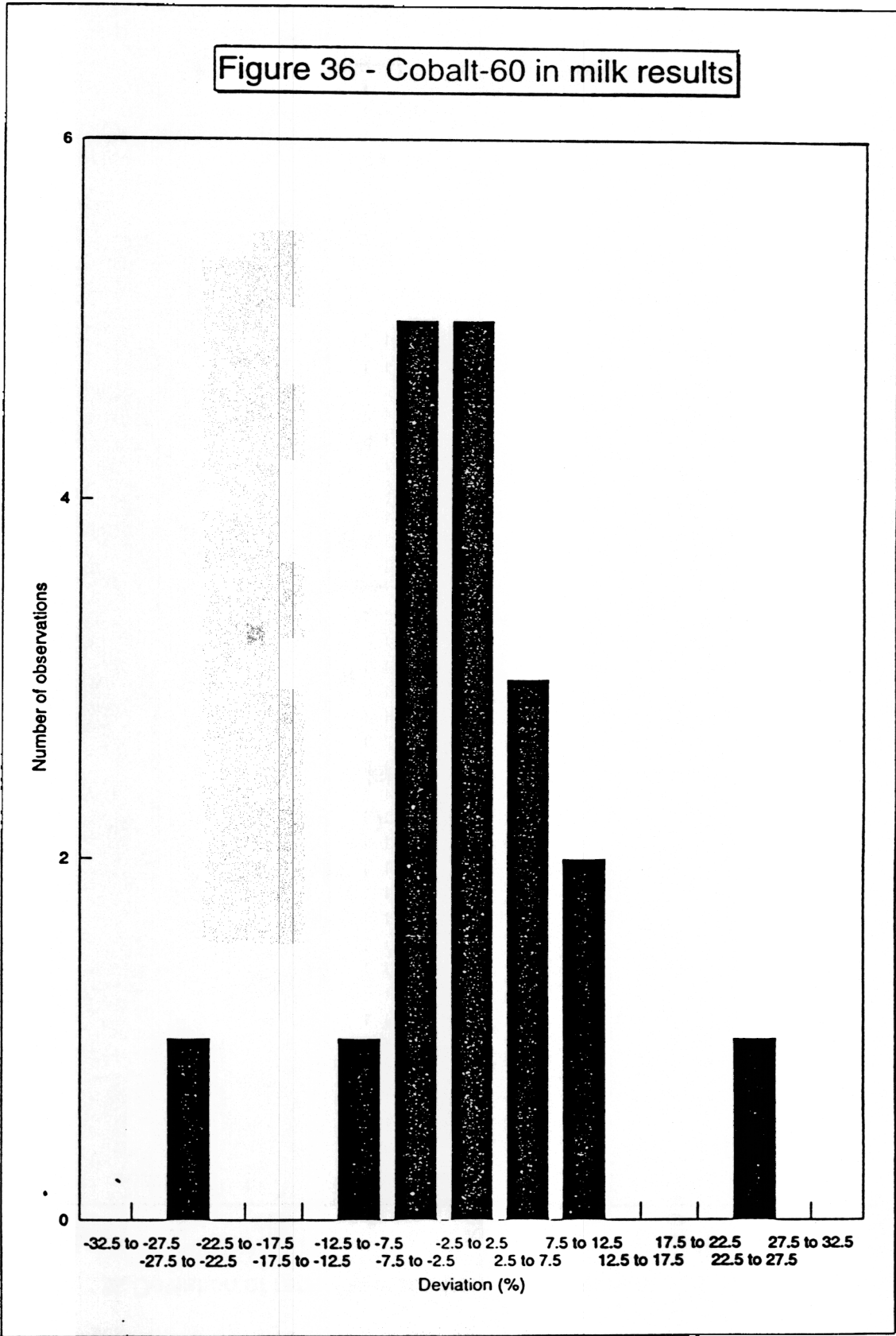


Figure 36 - Cobalt-60 in milk results



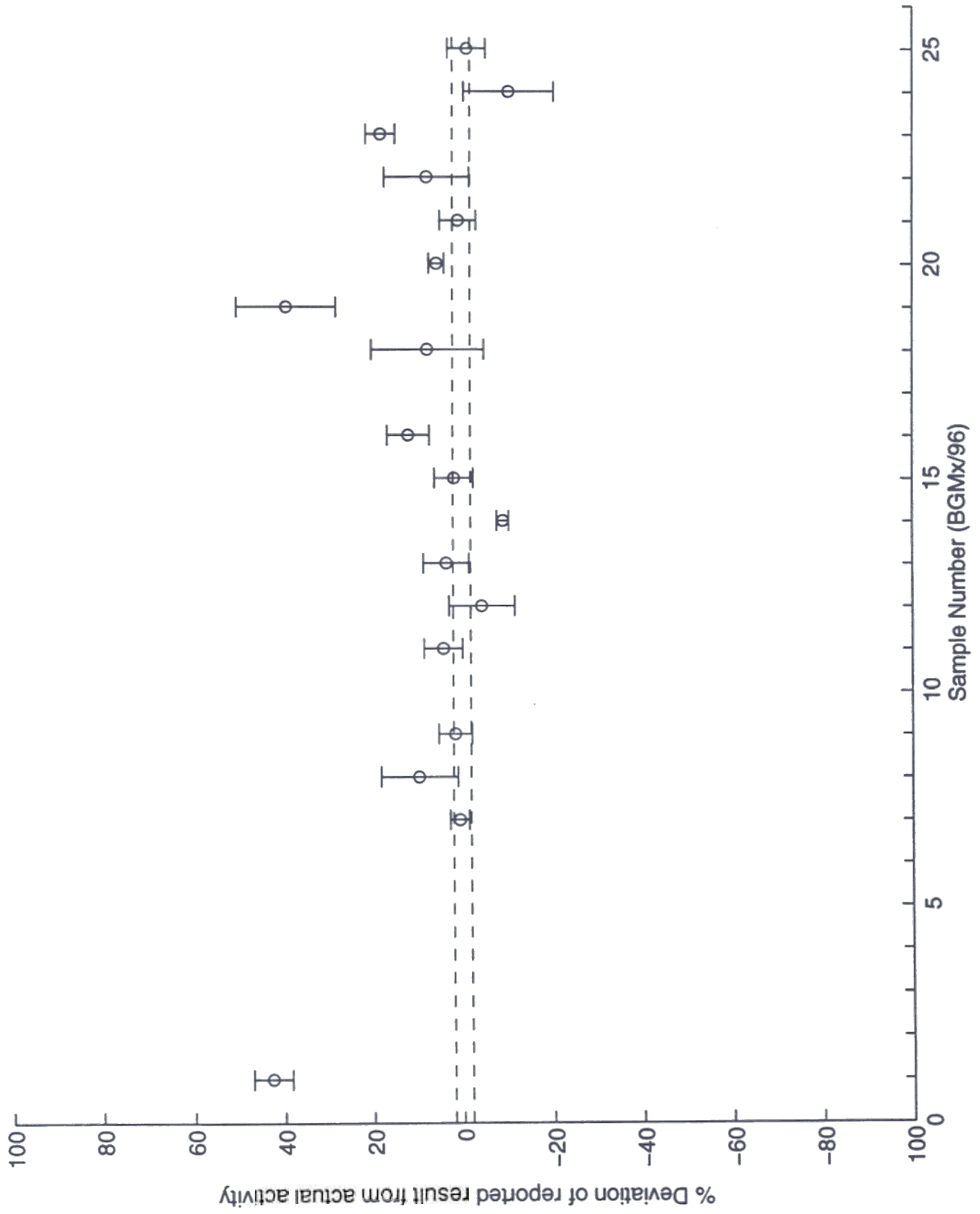


Figure 37 – Reported Sb-125 results (milk)

Figure 38 - Antimony-125 in milk results
(2 outside limits of plot)

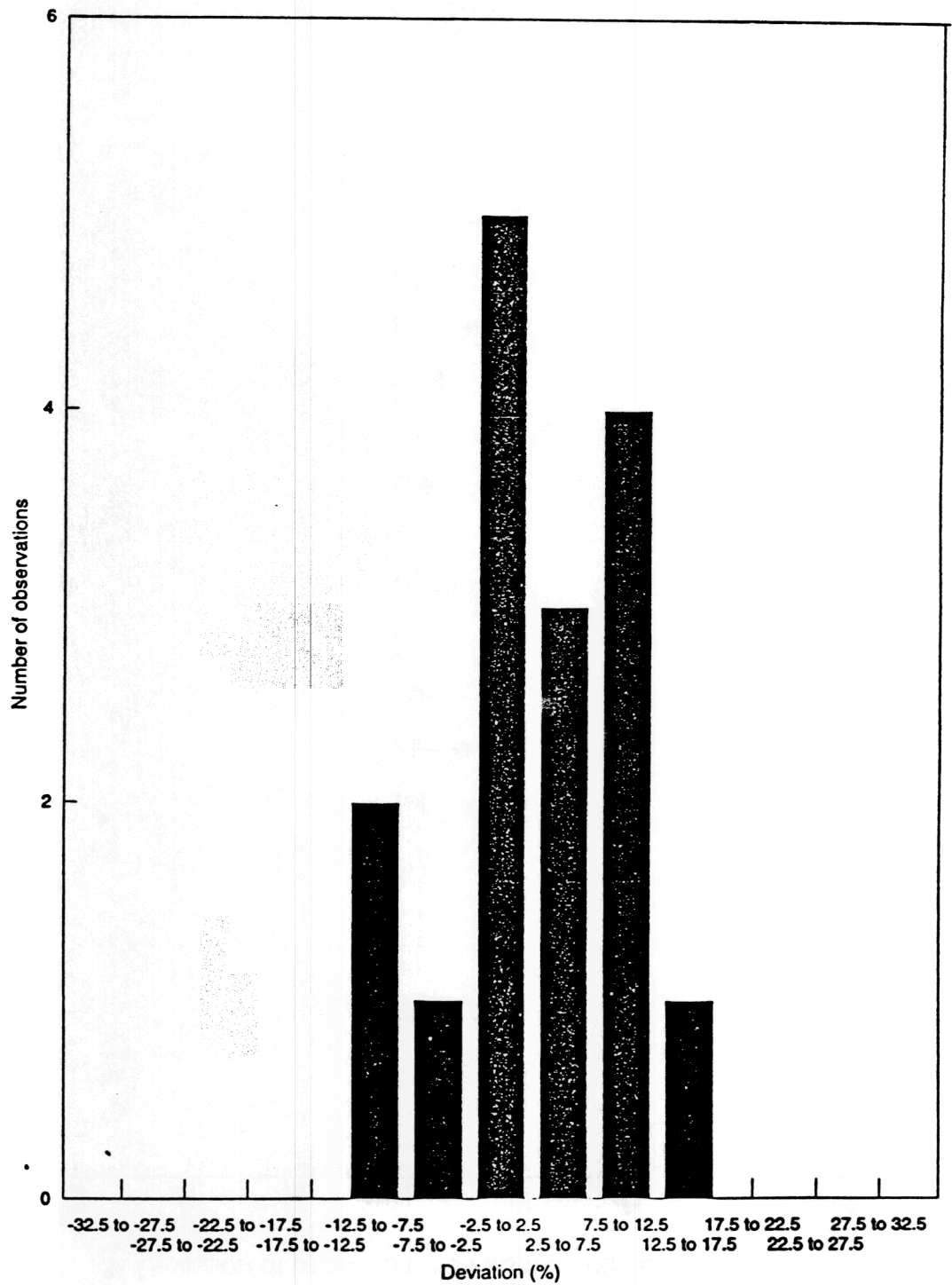


Figure 39 – Reported Cs-134 results (milk)

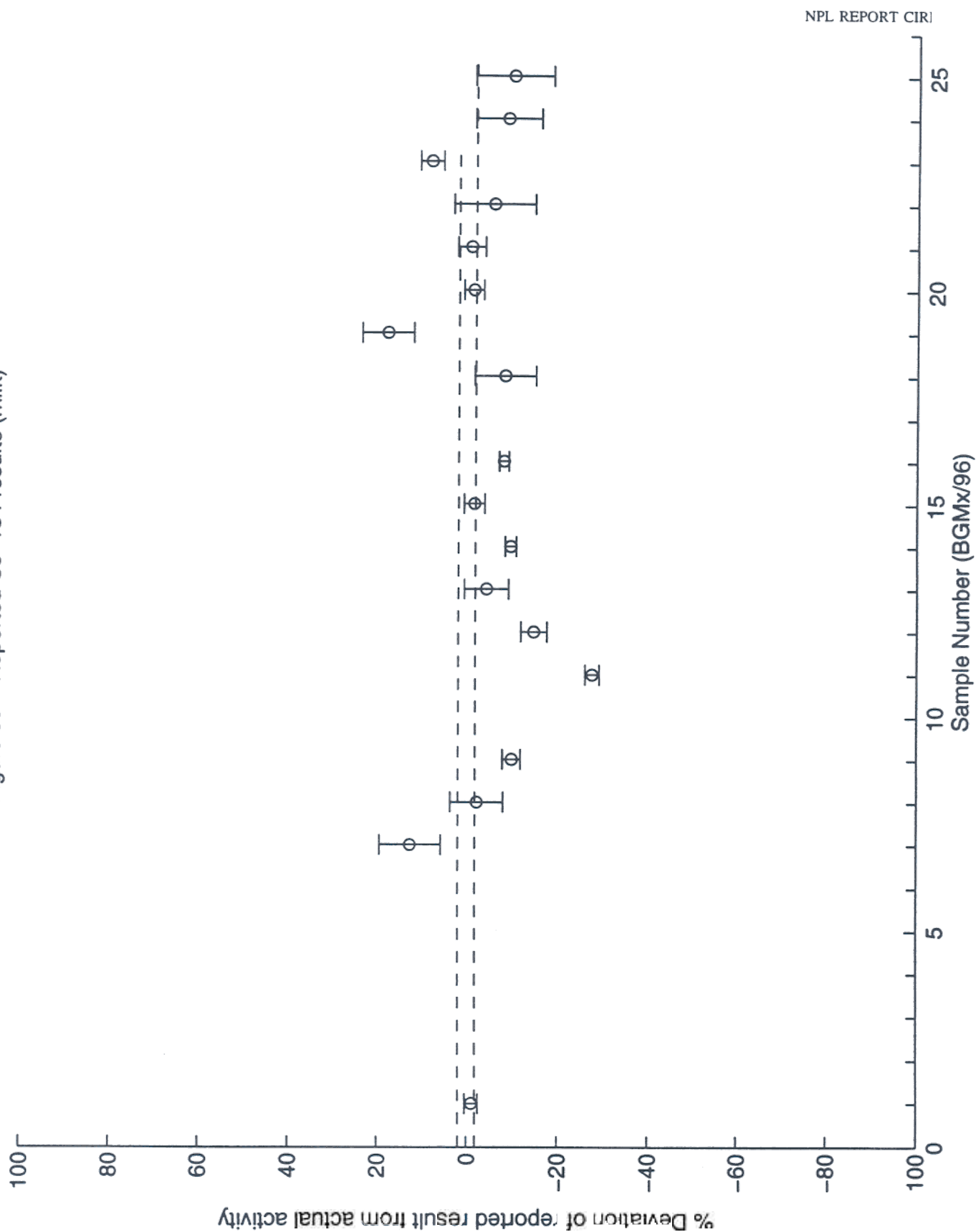


Figure 40 - Caesium-134 in milk results

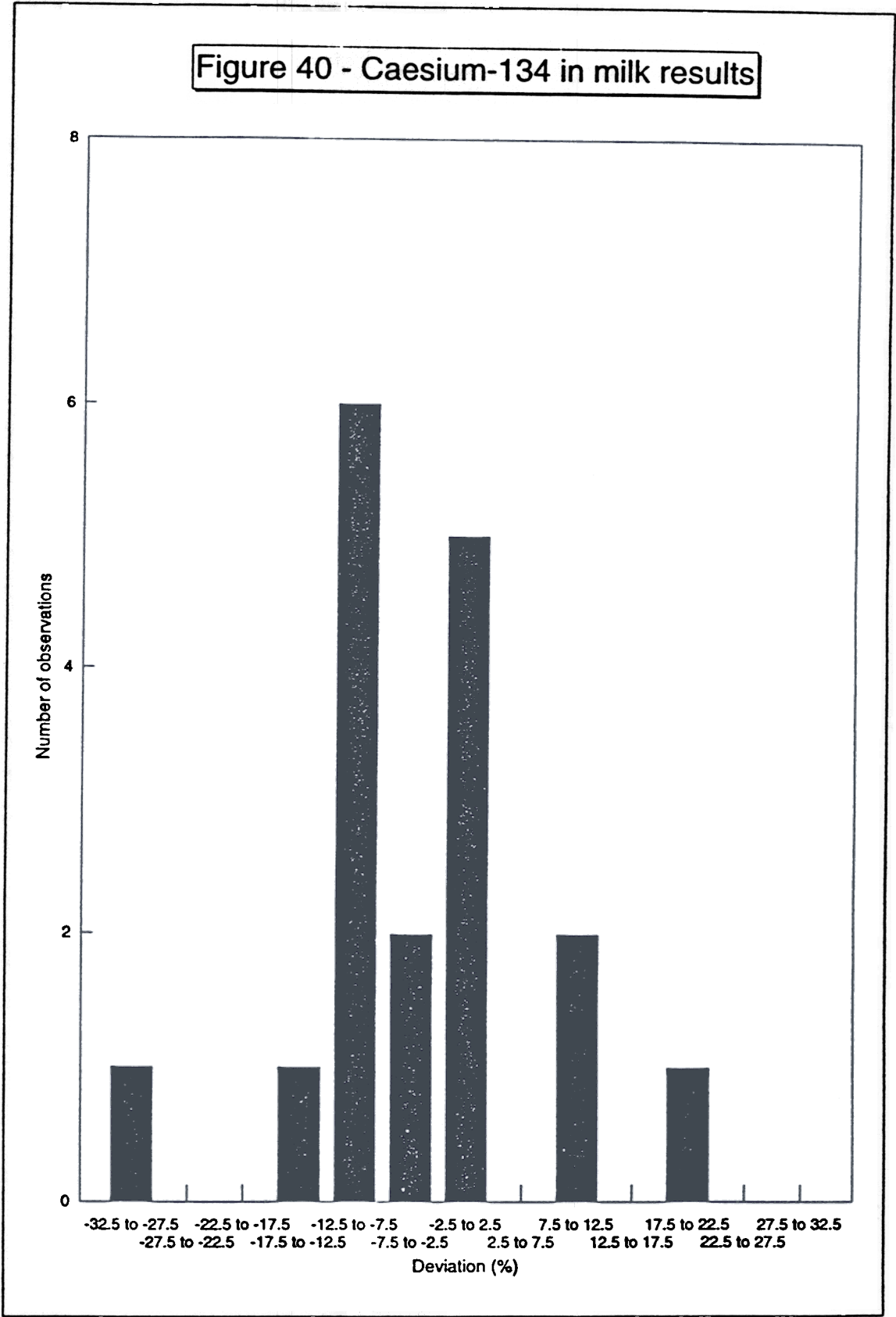


Figure 4. Reported Cs-137 results (milk)

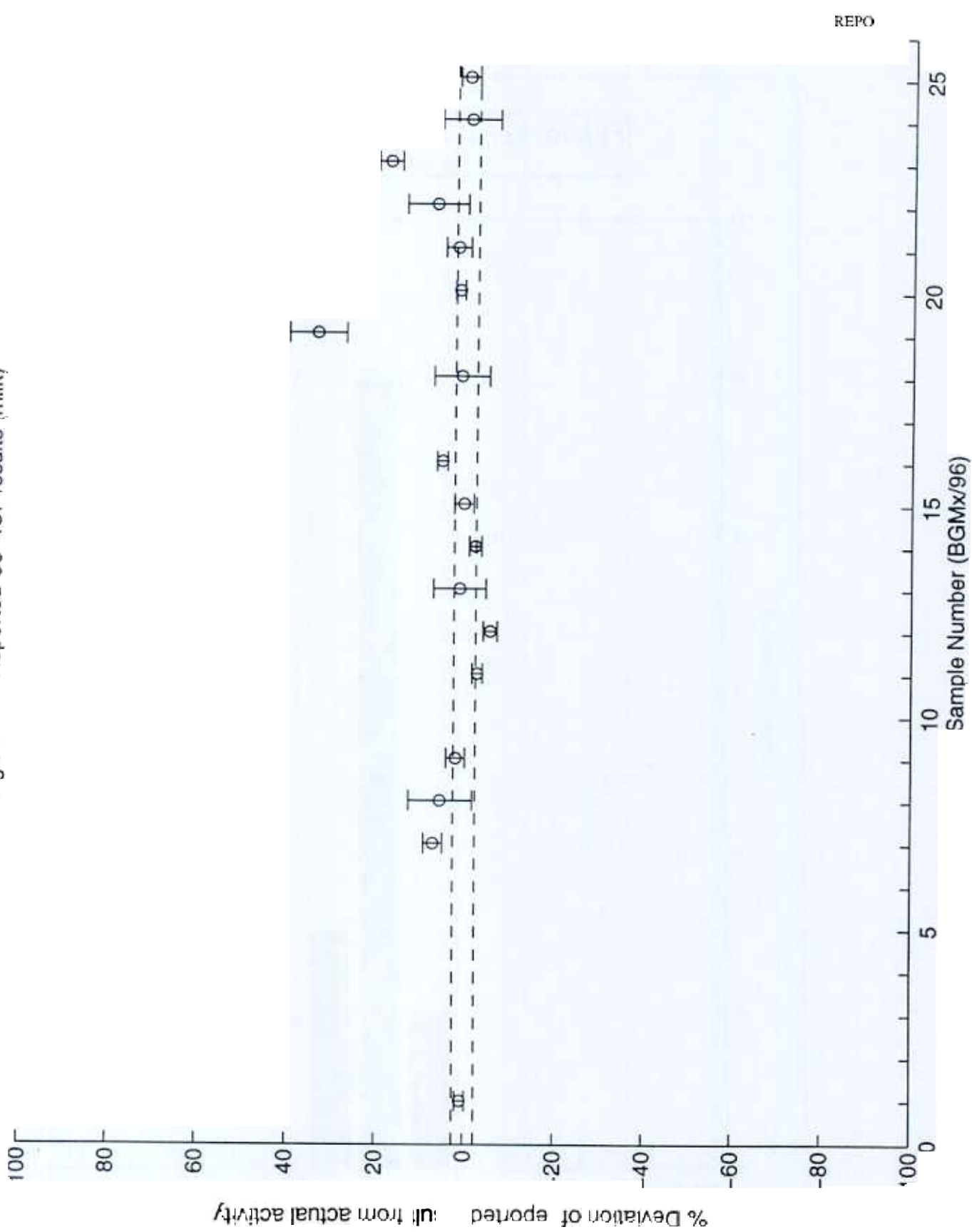


Figure 42 - Caesium-137 in milk results
(3 outside limits of plot)

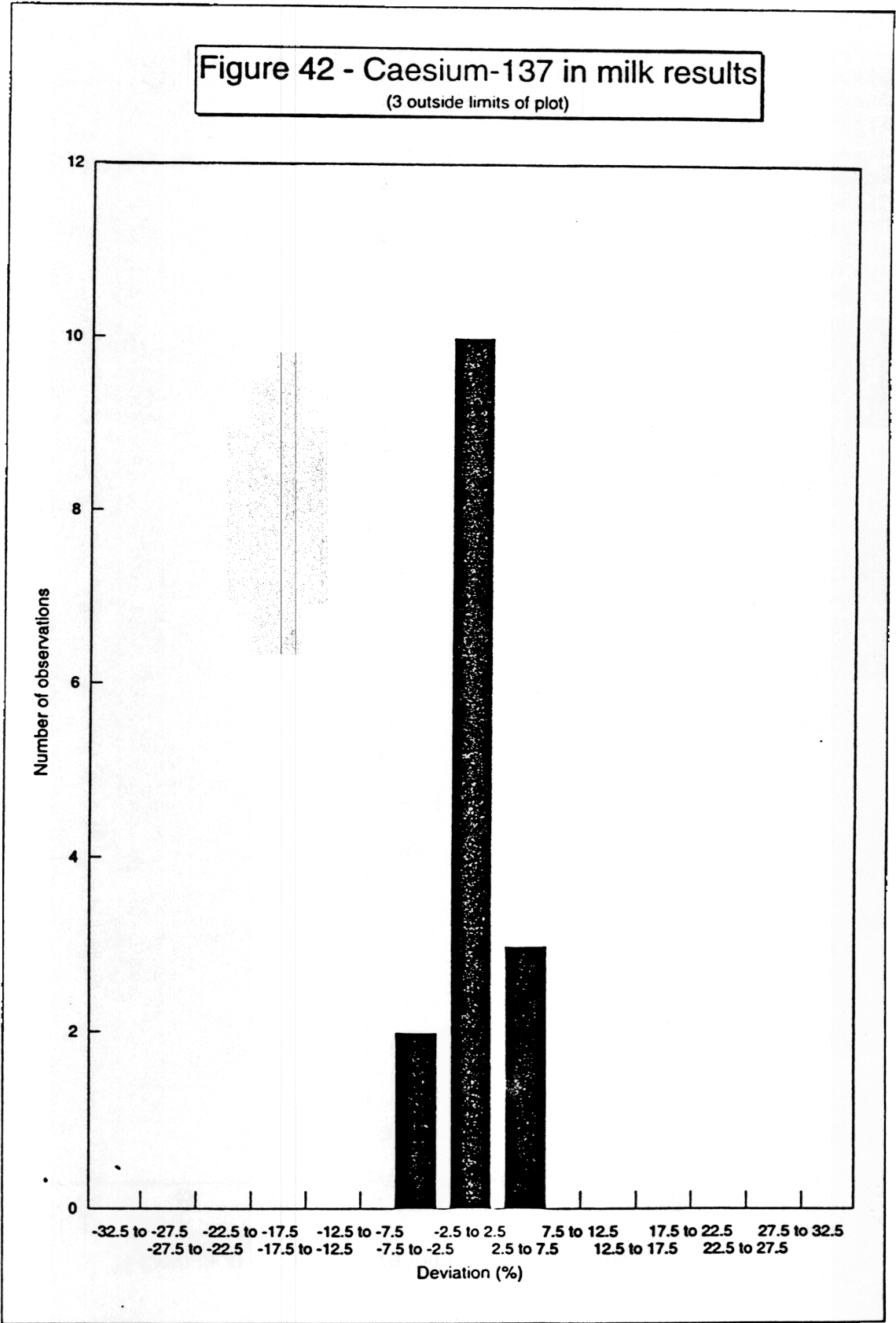


Figure 43 – Reported Eu-154 results (milk)

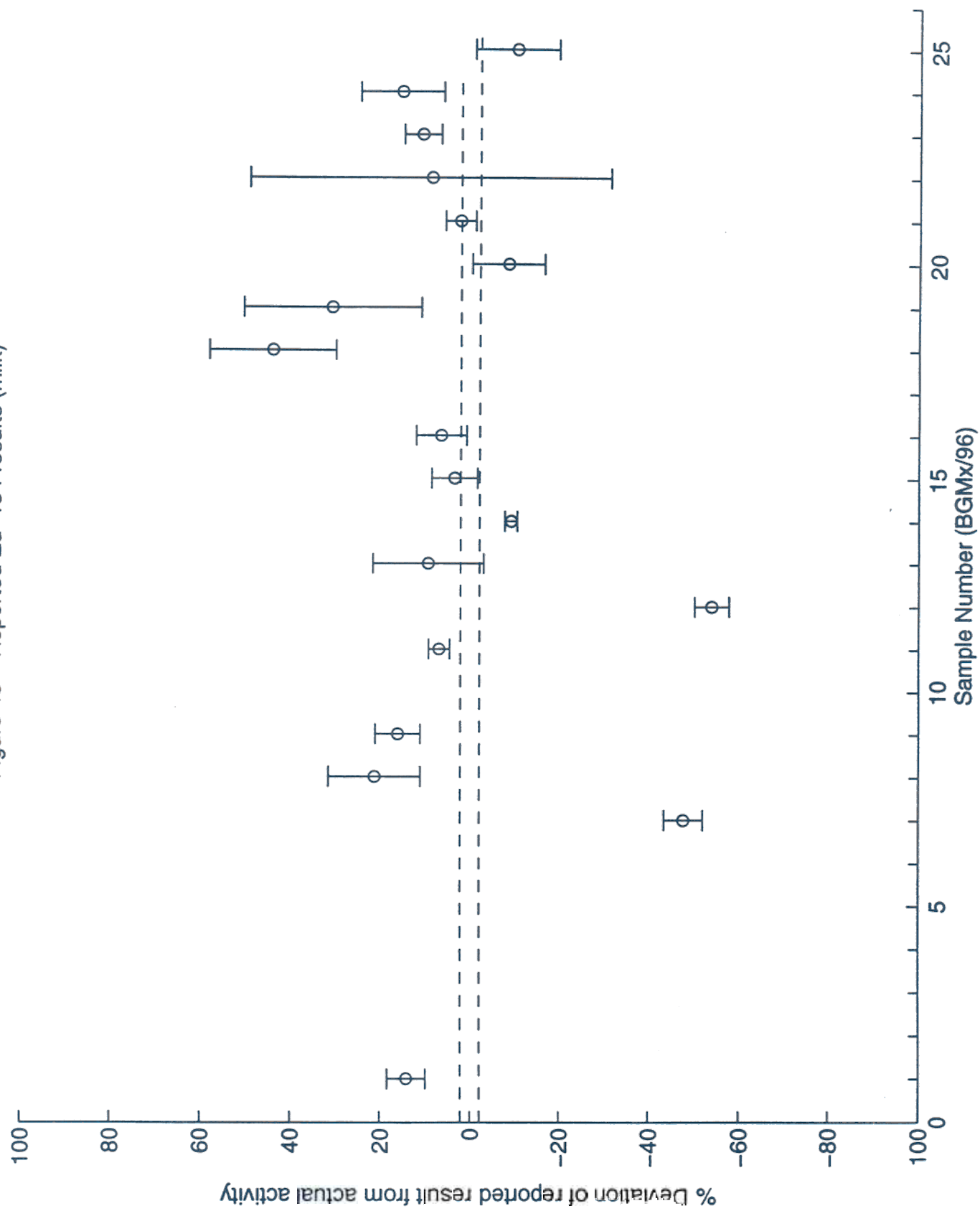


Figure 44 - Europium-154 in milk results
(3 outside limits of plot)

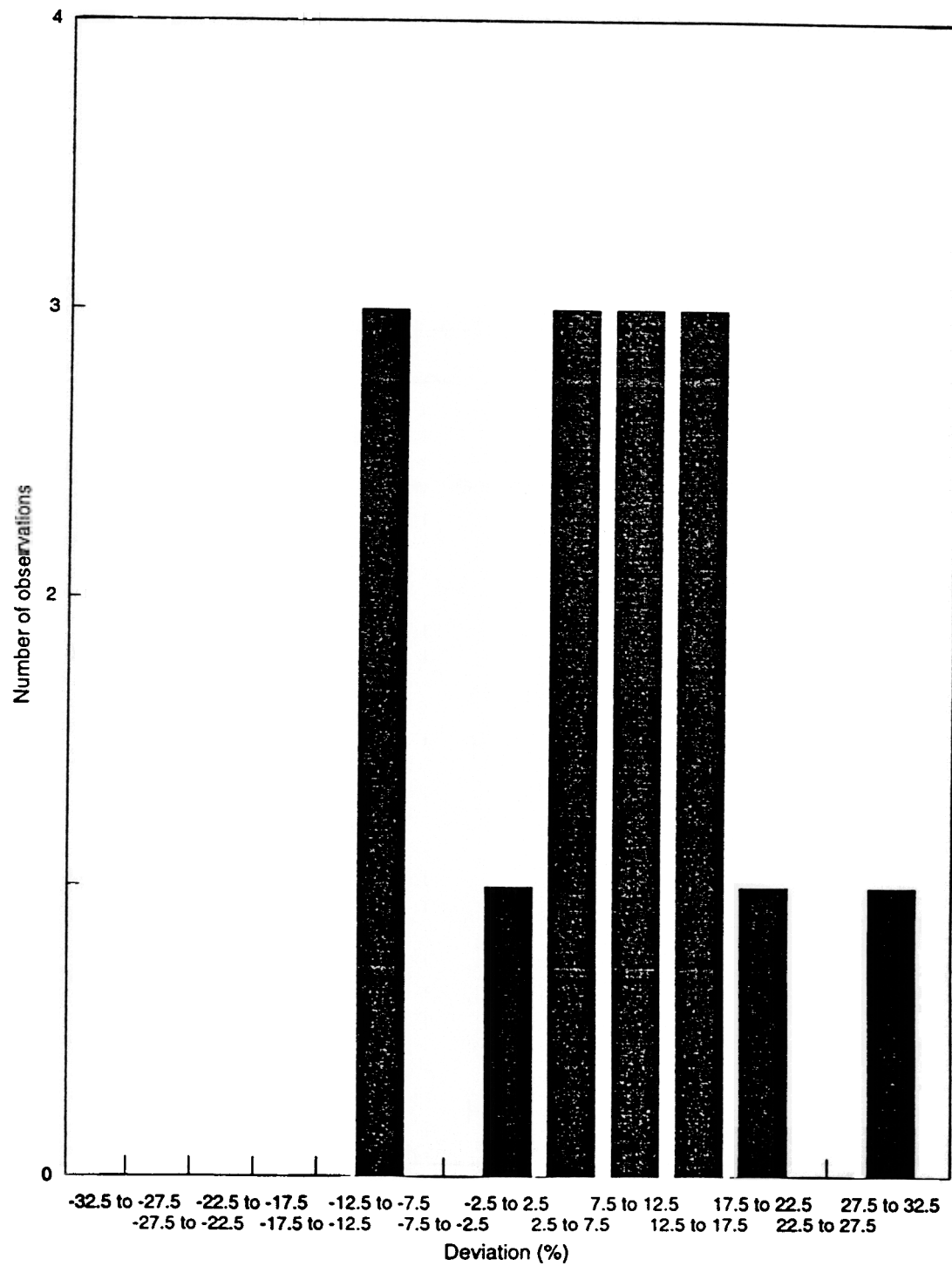


Figure 45 – Reported Eu-155 results (milk)

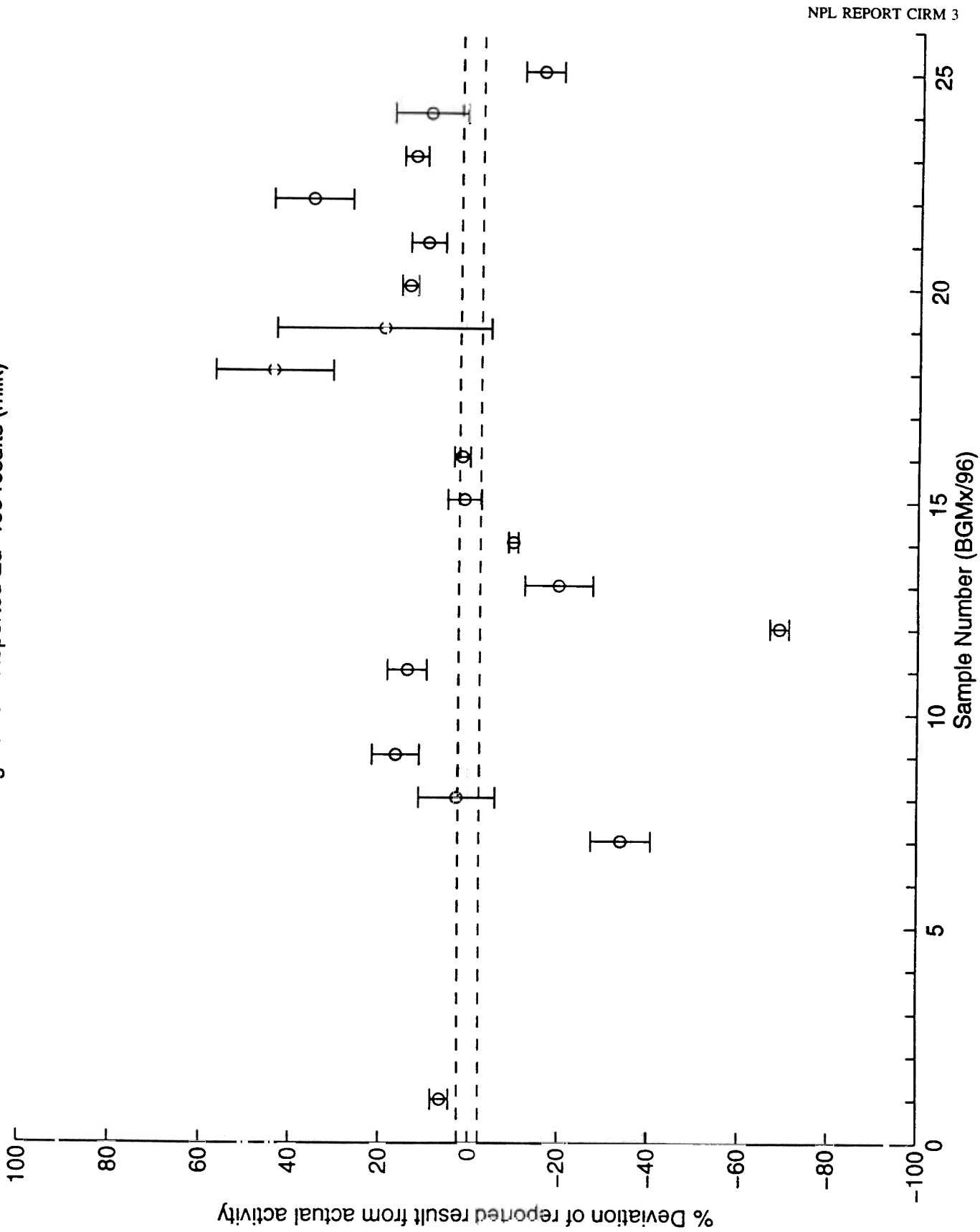
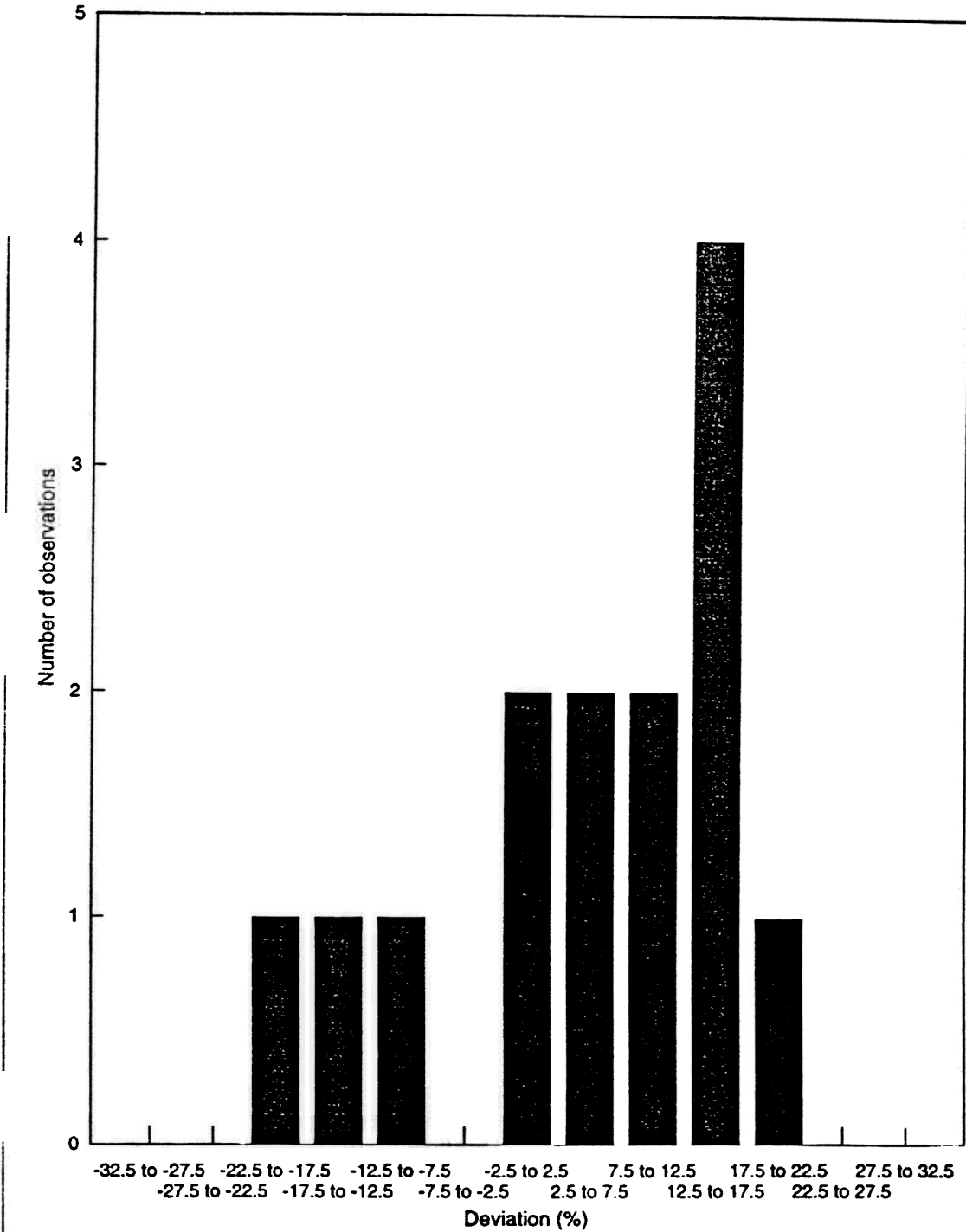


Figure 46 - Europium-155 in milk results
(4 outside limits of plot)



APPENDIX 1

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