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Environmental Radioactivity Proficiency Test Exercise 2019 – Final Report

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Environmental Radioactivity Proficiency Test Exercise 2019

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ABSTRACT

The results of NPL's twenty-fifth Environmental Radioactivity Proficiency Test Exercise are reported. Five different sample types were offered: an aqueous mixture of one alpha emitting radionuclide and three beta emitting radionuclides (designated 'AB'), an aqueous mixture of three alpha-emitting radionuclides ('A1'), an aqueous mixture of three beta-emitting radionuclides ('B1'), an aqueous mixture of four gamma-emitting radionuclides ('GH'), and a second aqueous mixture of four gamma-emitting radionuclides ('GL'). In total, over 450 results were submitted.

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This is a reissue for NPL Report IR57. Changes were made to the values in Table 7 and the discussion has been updated. The PMM for gross beta results for sample types AB and B1 were not assigned as NPL values and have been removed from participant results tables for clarity.

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Science Area Leader, Nuclear Metrology Group, Medical, Marine and Nuclear Department

Assigned Values (reference time 2019-06-01 1200 UTC)

Radionuclide (AB)	Assigned Value (Bq g^{-1})
^{63}Ni	1.989 ± 0.044
^{90}Sr	2.032 ± 0.011
^{147}Pm	16.92 ± 0.32
^{238}Pu	9.375 ± 0.042
Radionuclide (A1)	**Assigned Value (Bq kg^{-1})**
^{234}U	19.05 ± 0.48
^{235}U	0.671 ± 0.022
^{238}U	14.05 ± 0.36
Radionuclide (B1)	**Assigned Value (Bq g^{-1})**
^{3}H	0.565 ± 0.014
^{14}C	0.1720 ± 0.0024
^{99}Tc	0.2063 ± 0.0038
Radionuclide (GH)	**Assigned Value (Bq g^{-1})**
^{22}Na	16.67 ± 0.14
^{54}Mn	11.446 ± 0.086
^{133}Ba	16.940 ± 0.24
^{137}Cs	8.61 ± 0.13
Radionuclide (GL)	**Assigned Value (Bq kg^{-1})**
^{58}Co	34.64 ± 0.48
^{134}Cs	19.57 ± 0.56
^{210}Pb	15.00 ± 0.32
^{241}Am	2.508 ± 0.011

UNCERTAINTIES

The reported expanded uncertainty is based on a standard uncertainty multiplied by a coverage factor k = 2, providing a coverage probability of approximately 95 %. The uncertainty evaluation has been carried out in accordance with UKAS requirements.

CONTENTS

1. SUMMARY

This environmental radioactivity Proficiency Test Exercise (PTE) was the twenty-fifth in a series of annual exercises run by NPL over the last 30 years. The exercises help analysts to identify measurement problems and also support UKAS accreditations in this area. A range of sample types were made available during previous exercises. These have been mostly aqueous, but in recent years, solid materials have been introduced subject to availability.

Five sample types were made available for analysis in the 2019 PTE:

(i) **AB**: a mixture of one alpha-emitting radionuclide and three beta-emitting radionuclides
20 g of dilute nitric acid (1 – 20 Bq g^{-1} per radionuclide)

(ii) **A1:** a mixture of three alpha-emitting radionuclides
500 g of dilute nitric acid (0.5 – 25 Bq kg^{-1} per radionuclide)

(iii) **B1**: a mixture of three beta-emitting radionuclides
500 g of 0.01 M NaOH solution (0.1 – 2 Bq g^{-1} per radionuclide)

(iv) **GH**: a 'high-level' mixture of four gamma-emitting radionuclides
100 g of dilute nitric acid (1 – 20 Bq g^{-1} per radionuclide)

(v) **GL**: a 'low-level' mixture of four gamma-emitting radionuclides
500 g of dilute nitric acid (1 – 50 Bq kg^{-1} per radionuclide)

As in previous years, the main objective was to assess the performance of the participating laboratories. NPL acted as the exercise coordinator, preparing and distributing the samples to participants who measured the activity per unit mass of the radionuclides present in the samples. NPL then collected, analysed, and interpreted the results which were compiled into an exercise report.

Each participant was allocated a unique laboratory code number (if not already allocated in a previous PTE in this series) by NPL. This was done in confidence so that no third parties could identify which participant had which code number. NPL asked the participants to add their code numbers to the Reporting Forms so that the code numbers could be used by NPL to label the results in the final PTE report.

Each sample type was prepared in bulk by combining weighed aliquots of NPL radioactive standards with a weighed amount of carrier solution and then diluting the mixture further to achieve the target activity per unit mass. Dilution factors were measured gravimetrically and were verified radiometrically through counting sources prepared at the various dilution levels using either liquid scintillation counting or gamma spectrometry. The Assigned Value for each radionuclide was calculated by dividing the activity per unit mass of the original standard solution by the dilution factor(s). The bulk solution was subdivided into (typically) 50 bottles and homogeneity was checked by gamma spectrometry where applicable. Solution stability was checked by counting one or more bottles of each sample type at NPL at regular intervals throughout the course of the PTE; all solutions were found to be stable. The activities per unit mass of the radionuclides in the aqueous sample types were traceable to national standards of radioactivity, and therefore to the international measurement system.

After receipt of the results from the participants, the Power-Moderated Mean (PMM, Pommé, 2012) was calculated for each radionuclide / radionuclide type. This provides a more robust estimate than the weighted mean in the event of discrepant data sets. For mutually consistent data, the method approaches the weighted mean, the weights being the reciprocals of the variances associated with the measured values. For data suspected of inconsistency, the weighting is moderated by augmenting laboratory variances by a common amount and/or by

decreasing the power of weighting factors. For increasingly discrepant data sets, there is a smooth transition from the weighted mean to the arithmetic mean. The PMM was also calculated for the following quantities:

- Sample Type AB gross beta
- Sample Type B1 gross beta
- Sample Type A1 gross alpha

For cases where no Assigned Value was available from NPL measurements, a decision was made in each case as to whether or not to use the PMM as the Assigned Value. Note that consensus values based on the PMM are not traceable to national standards of radioactivity.

The dispatch of the samples was subcontracted to the following organisations:

The Courier Company (UK) Limited
11 James Way
Marshall Court
Milton Keynes MK1 1SU

DG Global Forwarding
Legacy House
Hanworth Trading Estate
Hampton Rd West
Feltham TW13 6DH

Circle Express
Unit 1
Polar Park
Bath Rd
West Drayton UB7 0EX

Note that, unless otherwise stated, all uncertainties quoted in this report are combined standard uncertainties with no coverage factor applied; the corresponding confidence interval is approximately 68 %.

2. TREATMENT OF DATA

The data were analysed using the same methods as in the 2018 exercise (Dean et al., 2019). The deviation 'D' from the assigned value from each laboratory value was calculated from:

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

The standard uncertainty (k = 1) 'u_D' of the deviation was calculated from:

$$u_{\mathrm{D}} = \frac{L}{N} \sqrt{\left(\frac{u_{\mathrm{L}}}{L} \right)^2 + \left(\frac{u_{\mathrm{N}}}{N} \right)^2} \quad [2]$$

The quantities zeta 'ζ', the relative uncertainty of a laboratory's value 'R_L' and the z-score 'z' were calculated from:

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

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

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

where:

L is the participant's value;
N is the Assigned Value;
u_{L} is the standard uncertainty of the participants' value;
u_{N} is the standard uncertainty of the Assigned Value;
σ_{p} is the standard uncertainty for proficiency assessment.

The value of the standard uncertainty for proficiency assessment σ_p is chosen by perception (viz. ISO 13528:2005 paragraph 6.3). It corresponds to a level of performance that NPL would wish laboratories to be able to achieve. It corresponds to a deviation D of 15 % (at a 99 % confidence level). In other words, any result with a deviation D smaller than ± 15 % passed the z test.

Note that the z-score presented is as defined in ISO 13528:2005 rather than the commonly understood z-score and is used to reject results based on a maximum percentage deviation.

The zeta and z-scores were used to determine whether the difference between the participant's value and the Assigned Value was significantly different from zero. The Interquartile Range outlier test (Harms and Gilligan, 2011) was used to determine whether the relative uncertainty R_{L} was significantly larger than the other values in the data set. Note that this test is unable to identify outliers if the data set is smaller than seven.

Results for which the absolute values of the zeta score and the *z*-score are both ≤ 2.576 and for which R_L is not significantly larger than the other values in the data set are taken to mean that the participant's value is 'in agreement' with the Assigned Value. These results are plotted in white in this report.

If (i) R_L is significantly larger than the other values in the data set, or (ii) the result passes the zeta test but not the *z*-test (i.e., there is a large deviation from the Assigned Value combined with a large uncertainty), or (iii) the result passes the *z*-test but not the zeta test (where there is a small deviation from the Assigned Value and a small uncertainty), the participant's value is classified as 'questionable' (plotted in yellow).

If the absolute values of both the zeta score and the *z*-score are greater than 2.576, then the participant's value is classified as 'discrepant' from the Assigned Value (plotted in red), regardless of the value of R_L.

Table 1 Summary of data classification criteria

zeta test	**R_L test**	***z* test**	**Classification**
pass	pass	pass	in agreement
pass	fail	pass	questionable
fail	pass	pass	questionable
pass	-	fail	questionable
fail	-	fail	discrepant

3. SUMMARY OF PARTICIPANTS' RESULTS

The PMM of the participant datasets for each radionuclide are compared to those of the NPL Assigned Values in Tables 2-6. The tests as described in section 2 are used to assess the agreement between these values. The reference time is 2019-06-01 1200 UTC.

Table 2 AB summary

Radionuclide (AB)	NPL Assigned Values (Bq g^{-1})	PMM (Bq g^{-1})	Deviation (%)	Zeta	Critical Value
^{63}Ni	1.989 ± 0.022	2.009 ± 0.037	1.0	0.46	2.85
^{90}Sr	2.0324 ± 0.0054	2.015 ± 0.026	-0.9	-0.66	2.79
^{147}Pm	16.92 ± 0.16	15.7 ± 2.5	-7.3	-0.49	4.03
^{238}Pu	9.375 ± 0.021	9.15 ± 0.10	-2.4	-2.21	2.85

Table 3 A1 summary

Radionuclide (A1)	NPL Assigned Values (Bq kg^{-1})	PMM (Bq kg^{-1})	Deviation (%)	Zeta	Critical Value
^{234}U	19.05 ± 0.24	18.76 ± 0.12	-1.5	-1.09	2.58
^{235}U	0.671 ± 0.011	0.6500 ±0.0035	-3.1	-1.82	2.58
^{238}U	14.05 ± 0.18	13.958 ± 0.062	-0.7	-0.48	2.58

Table 4 B1 summary

Radionuclide (B1)	NPL Assigned Values (Bq g^{-1})	PMM (Bq g^{-1})	Deviation (%)	Zeta	Critical Value
^{3}H	0.5655 ± 0.0071	0.5578 ± 0.0038	-1.4	-0.96	2.58
^{14}C	0.1720 ± 0.0012	0.1666 ± 0.0027	-3.2	-1.86	2.79
^{99}Tc	0.2063 ± 0.0019	0.2032 ± 0.0048	-1.5	-0.60	2.92

Table 5 GH summary

Radionuclide (GH)	NPL Assigned Values (Bq g^{-1})	PMM (Bq g^{-1})	Deviation (%)	Zeta	Critical Value
^{22}Na	16.672 ± 0.068	16.09 ± 0.15	-3.5	-3.59	2.72
^{54}Mn	11.446 ± 0.043	11.526 ± 0.093	0.7	0.78	2.72
^{133}Ba	16.94 ± 0.12	16.32 ± 0.13	-3.7	-3.60	2.63
^{137}Cs	8.612 ± 0.064	8.690 ± 0.047	0.9	0.99	2.58

Table 6 GL summary

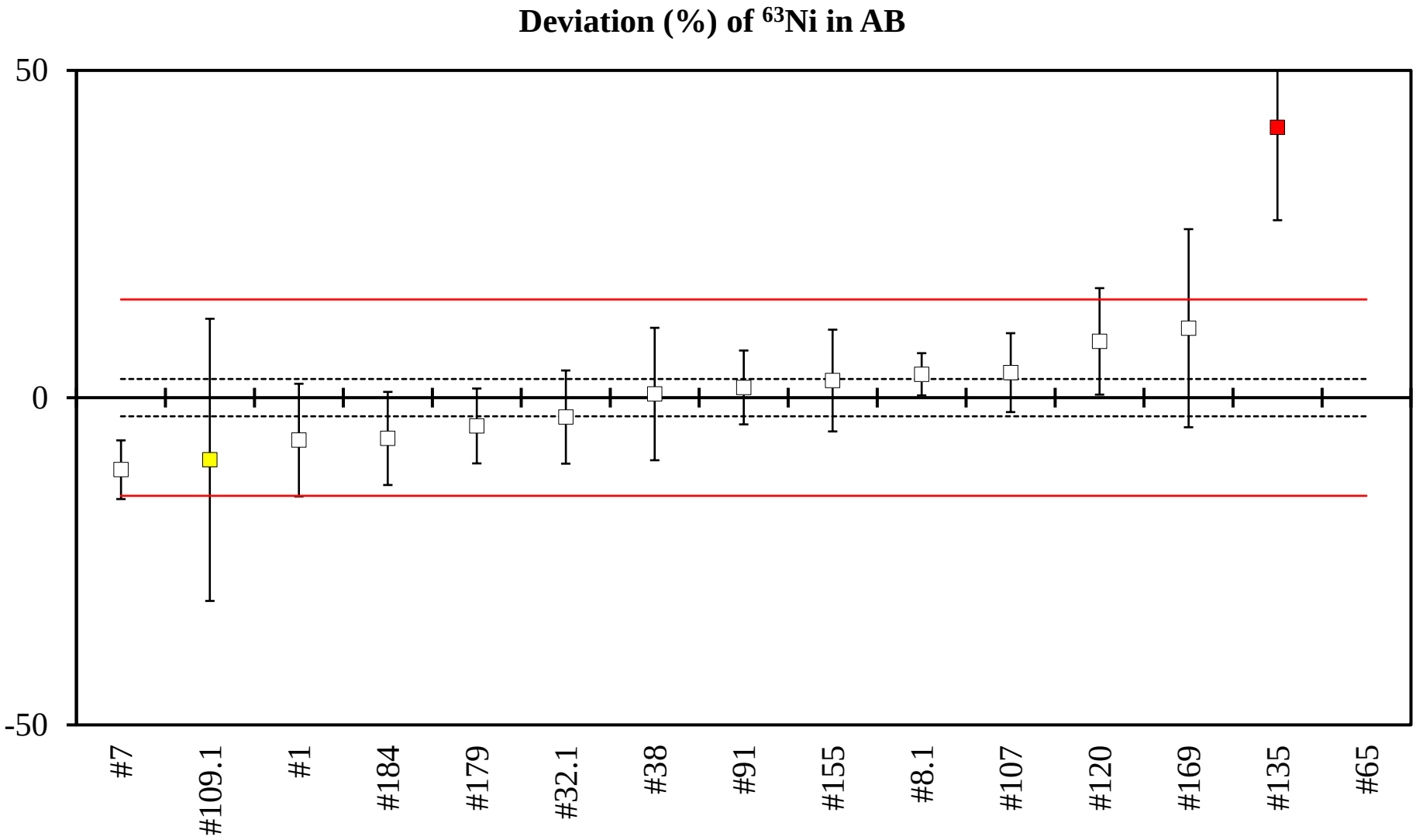
Radionuclide (GL)	NPL Assigned Values (Bq kg^{-1})	PMM (Bq kg^{-1})	Deviation (%)	Zeta	Critical Value
^{58}Co	34.64 ± 0.24	34.91 ± 0.46	0.8	0.52	2.72
^{134}Cs	19.57 ± 0.28	19.33 ± 0.16	-1.2	-0.74	2.58
^{210}Pb	15.00 ± 0.16	15.26 ± 0.52	1.7	0.47	2.81
^{241}Am	2.5082 ± 0.0054	2.559 ± 0.038	2.0	1.30	2.76

Table 7 Gross radionuclide measurements summary

Measurement	PMM
Gross beta (AB)	10.9 ± 2.0 Bq g^{-1} - Value not used (see Section 11)
Gross alpha (A1)	30.5 ± 1.8 Bq kg^{-1}
Gross beta (B1)	0.48 ± 0.13 Bq g^{-1} - Value not used (see Section 11)

A decision was made to not use the PMM as the Assigned Value for either of the gross beta measurements due to the limited number of results submitted, the spread of those results and the variation in measurement techniques used. The values provided in Table 7 are the PMM of the submitted results and are not traceable to national standards of radioactivity. The PMM of the gross beta measurements is provided as an indicator and has not been used for performance assessment. It is for this reason results for gross beta measurements will not appear in the following deviation plots and no assigned value will appear in participant tables.

4. Alpha Beta (AB) Deviation Plots


Deviation (%) of 63Ni in AB
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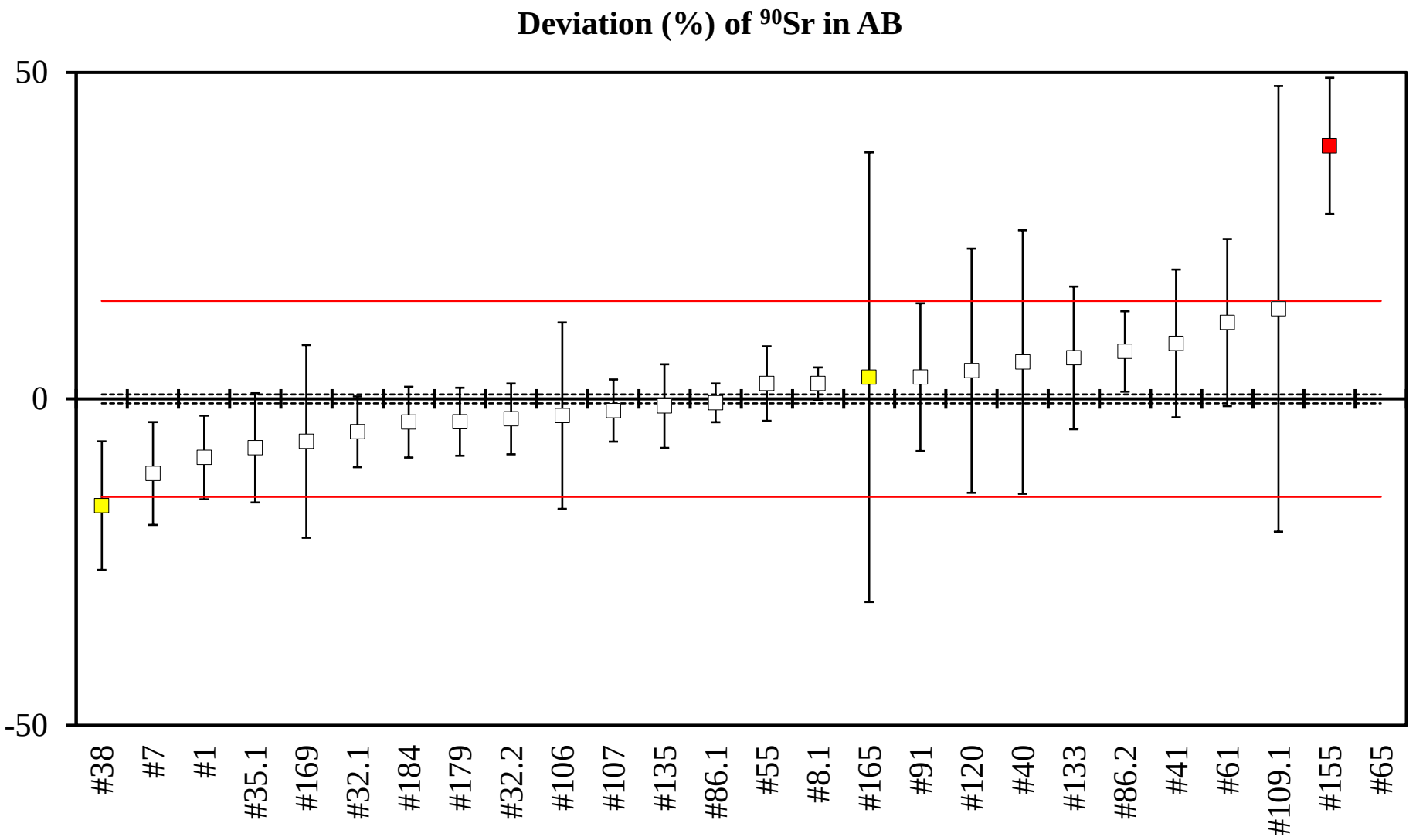
0
-50
#7
#109.1
#1
#184
#179
#32.1
#38
#91
#155
#8.1
#107
#120
#169
#135
#65


Deviation (%) of 90Sr in AB
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#7
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#35.1
#169
#32.1
#184
#179
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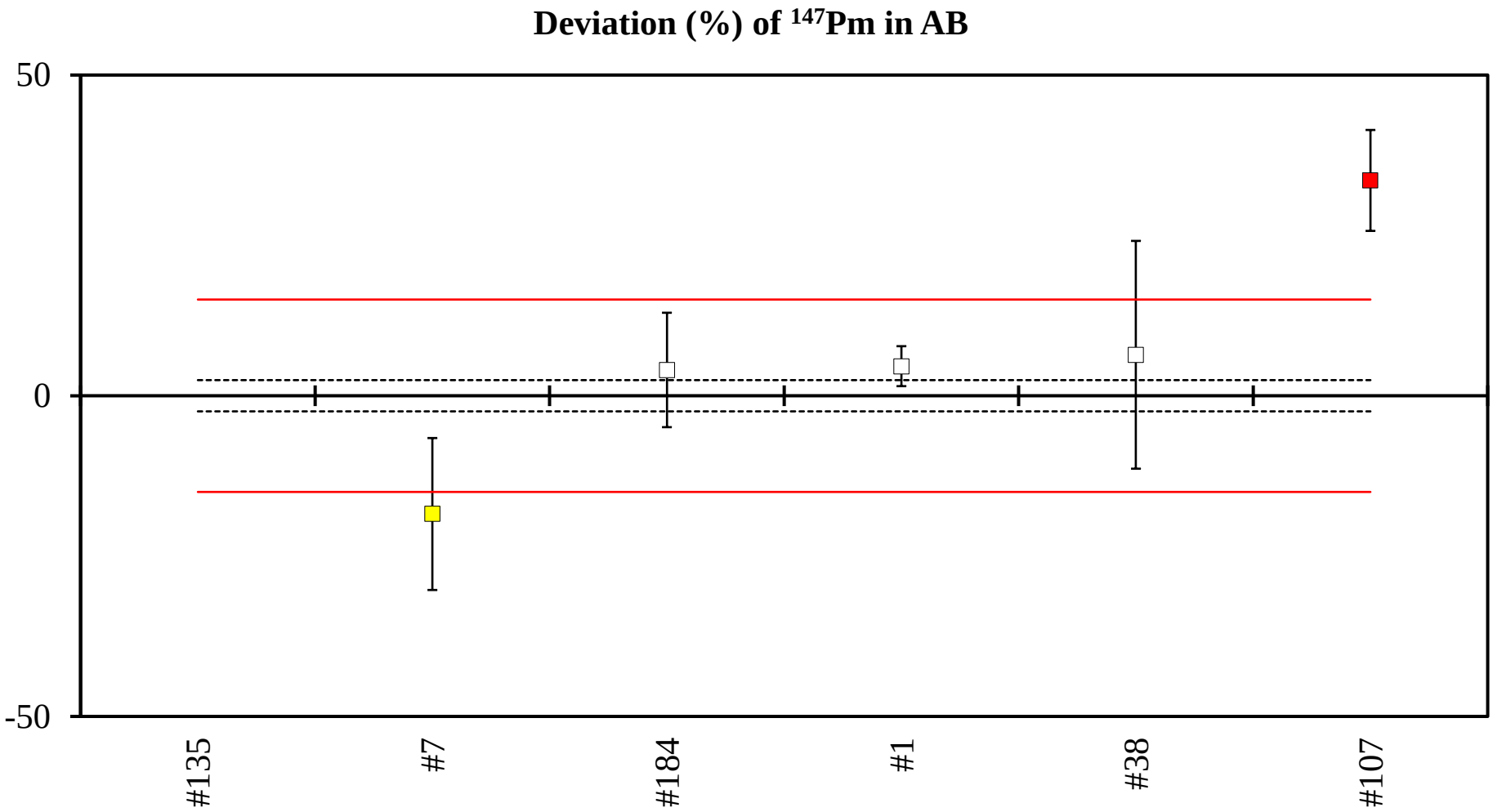
#106
#107
#135
#86.1
#55
#8.1
#165
#91
#120
#40
#133
#86.2
#41
#61
#109.1
#155
#65


Deviation (%) of 147Pm in AB
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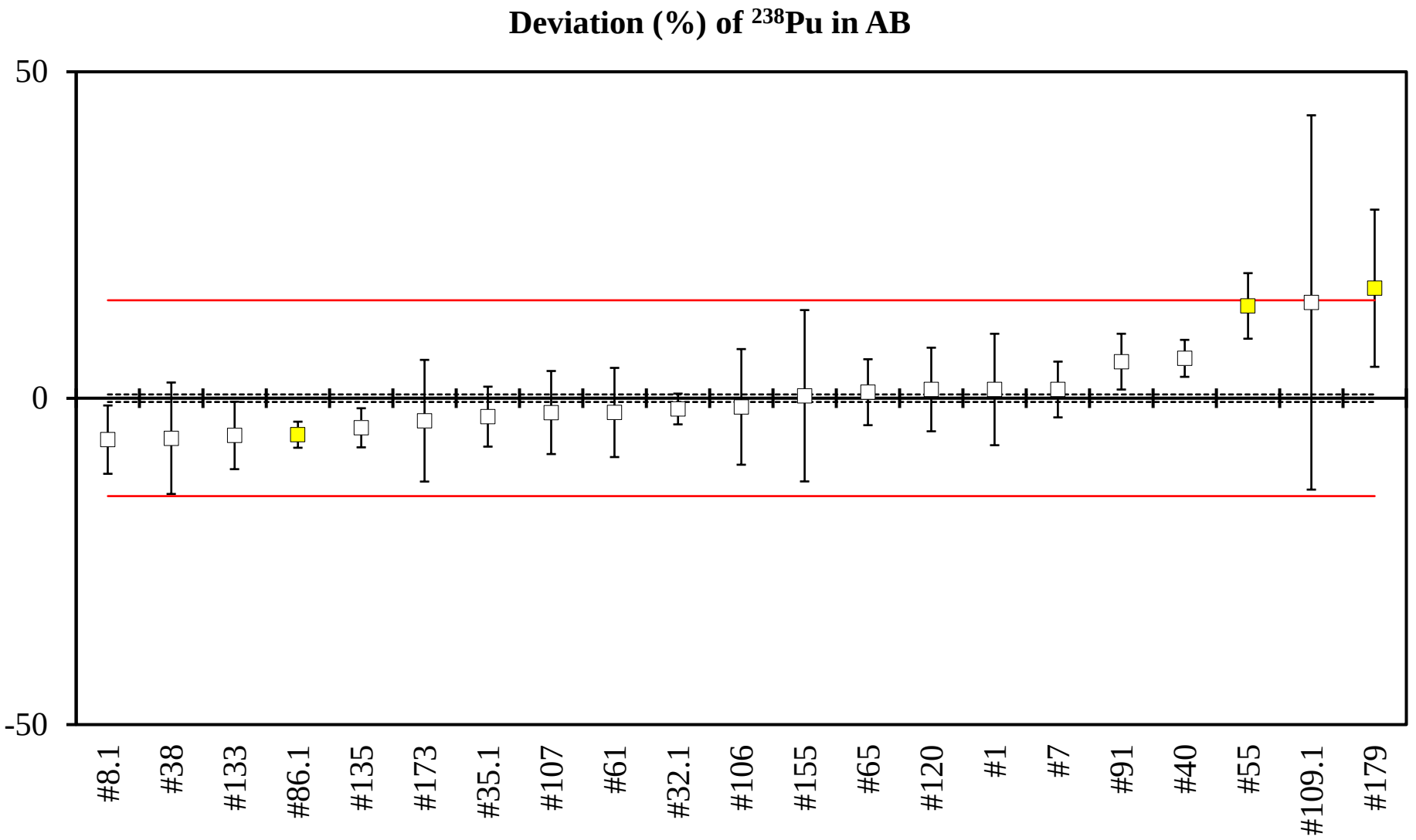
0
-50
#135
#7
#184
#1
#38
#107


Deviation (%) of 238Pu in AB
50
0
-50
#8.1
#38
#133
#86.1
#135
#173
#35.1
#107
#61
#32.1
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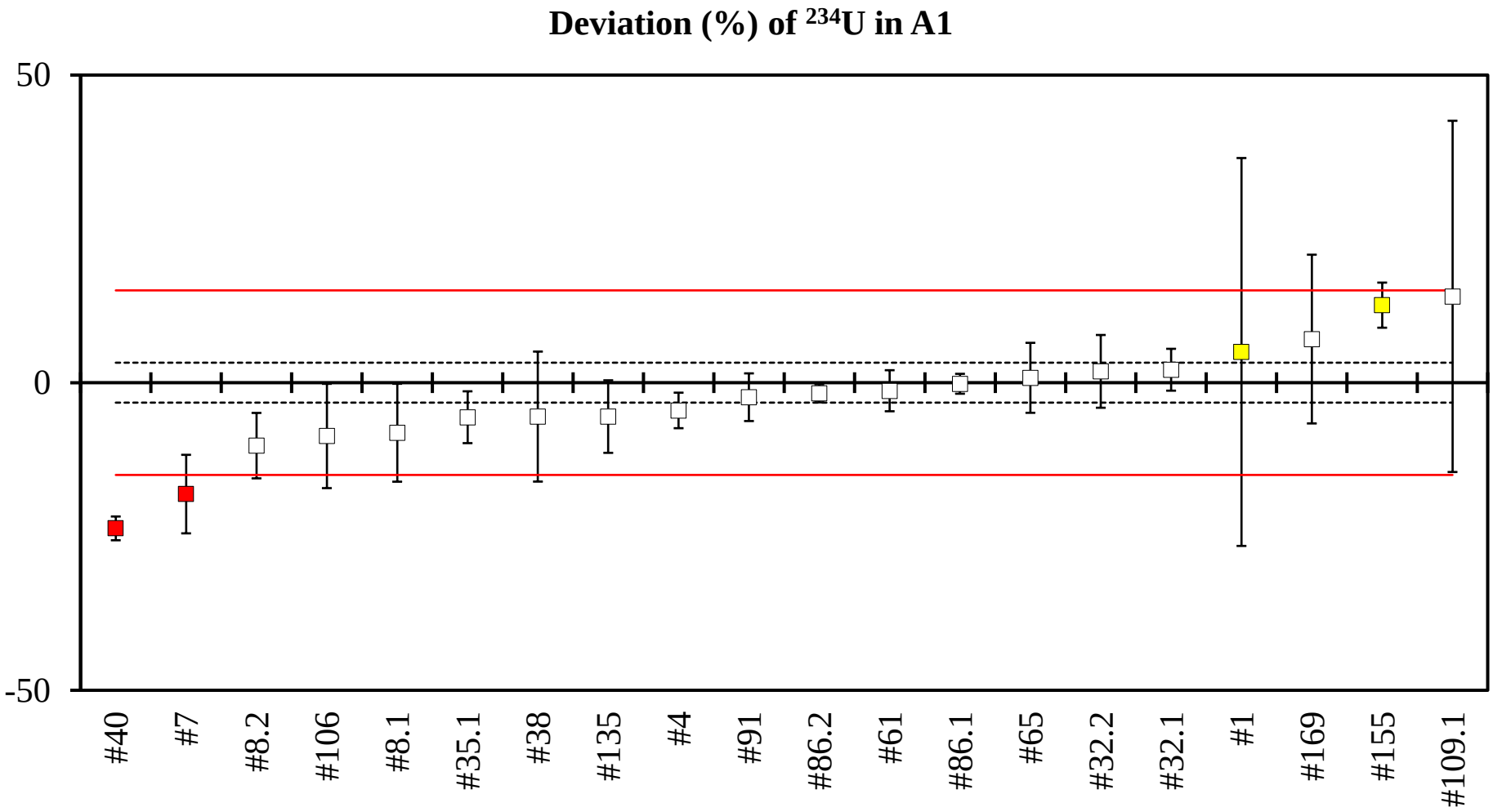
#155
#65
#120
#1
#7
#91
#40
#55
#109.1
#179

5. Alpha One (A1) Deviation Plots


Deviation (%) of 234U in A1
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0
-50
#40
#7
#8.2
#106
#8.1
#35.1
#38
#135
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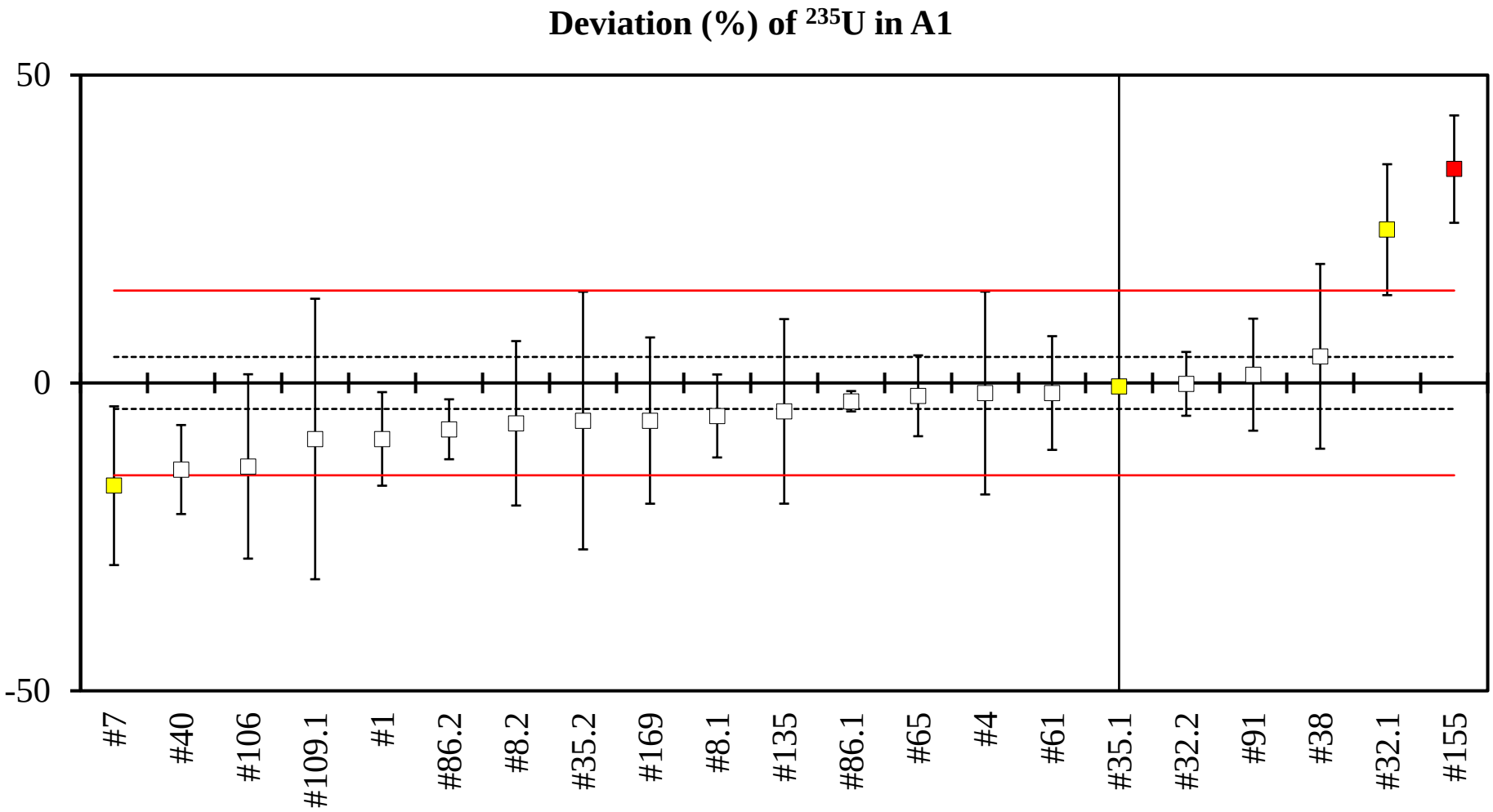
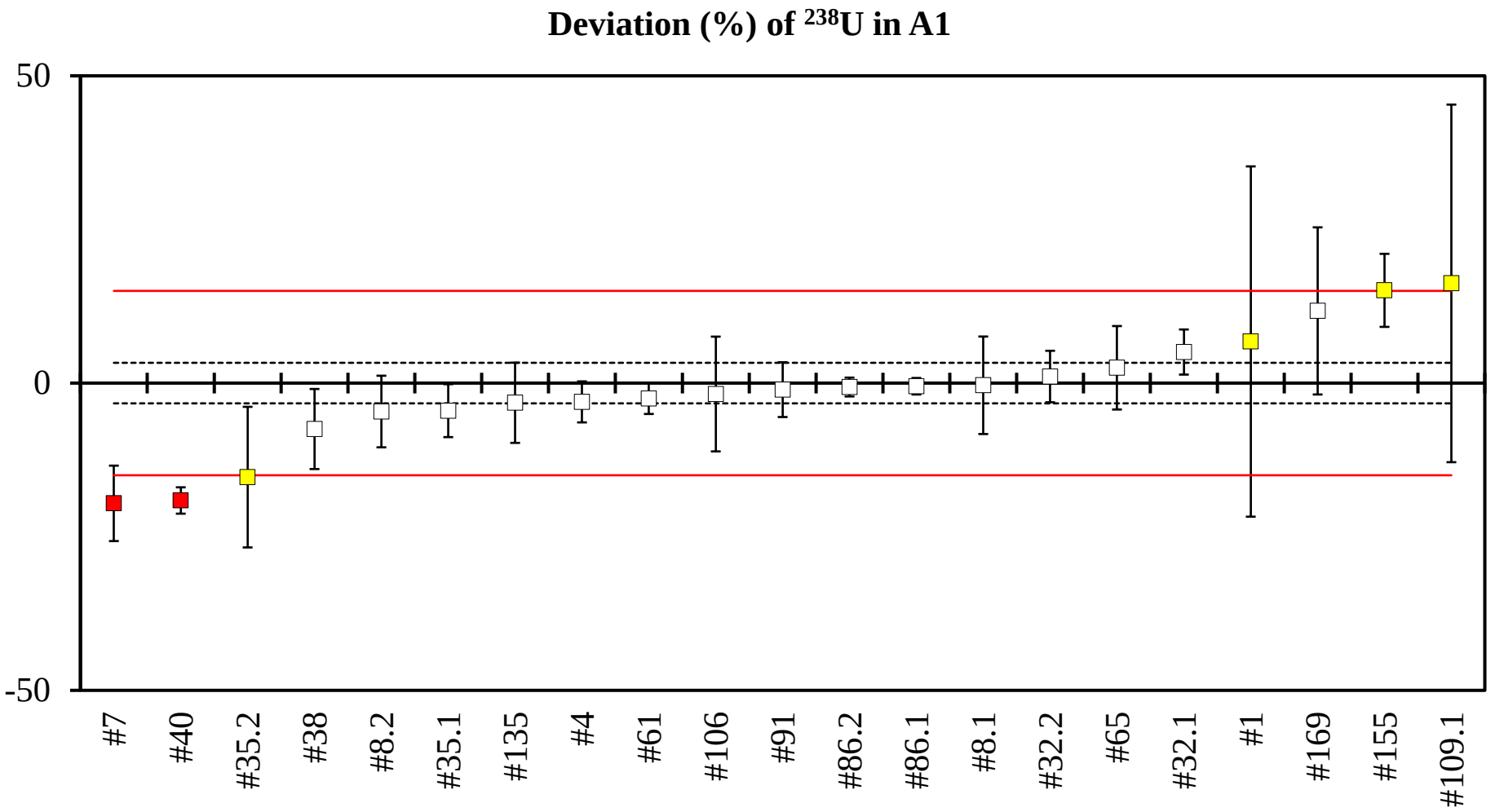
#32.2
#32.1
#1
#169
#155
#109.1


Deviation (%) of 235U in A1
50
0
-50
#7
#40
#106
#109.1
#1
#86.2
#8.2
#35.2
#169
#8.1
#135
#86.1
#65
#4
#61
#35.1
#32.2
#91
#38
#32.1
#155


Deviation (%) of 238U in A1
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0
-50
#7
#40
#35.2
#38
#8.2
#35.1
#135
#4
#61
#106
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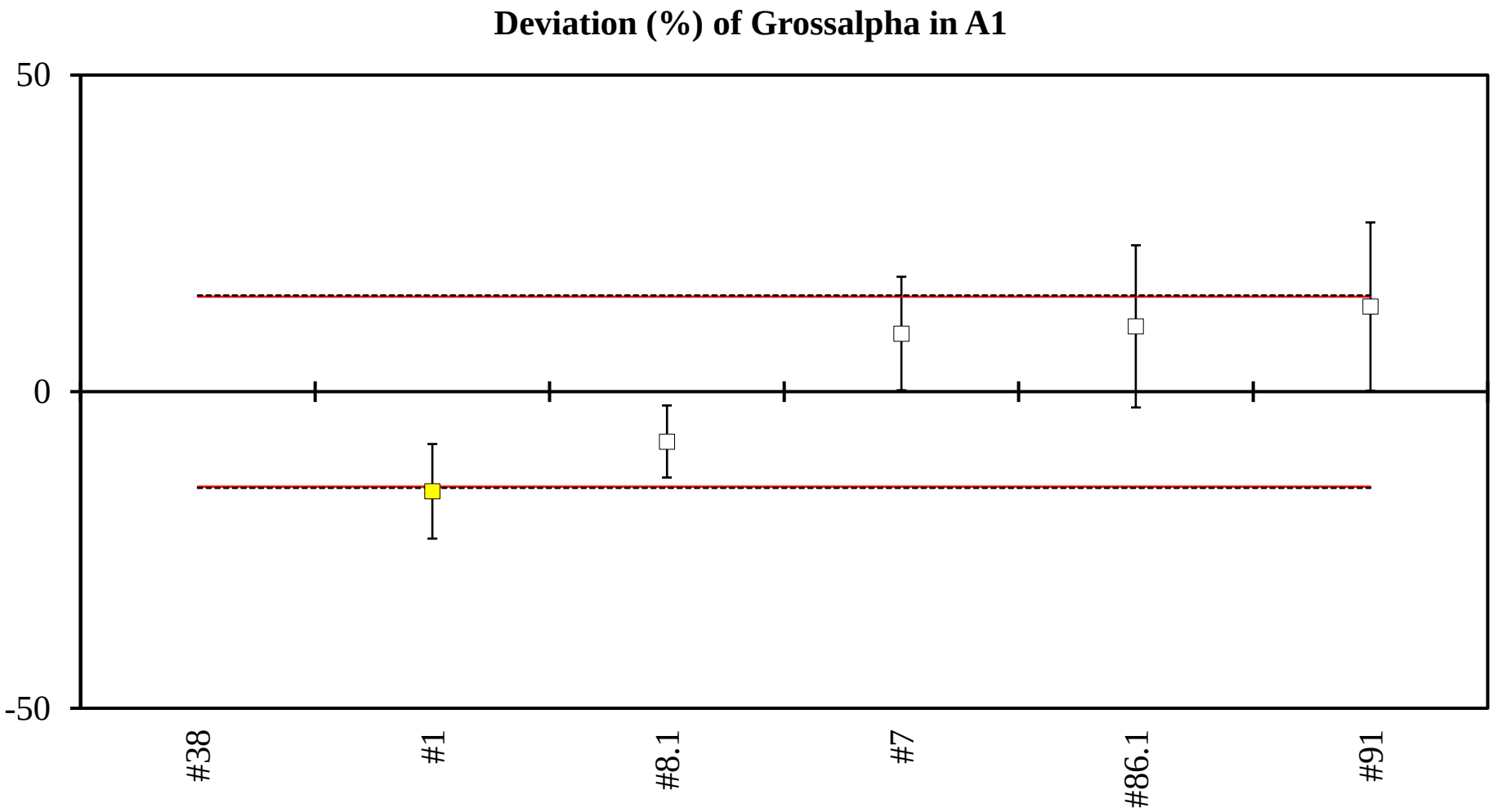
#65
#32.1
#1
#169
#155
#109.1


Deviation (%) of Grossalpha in A1
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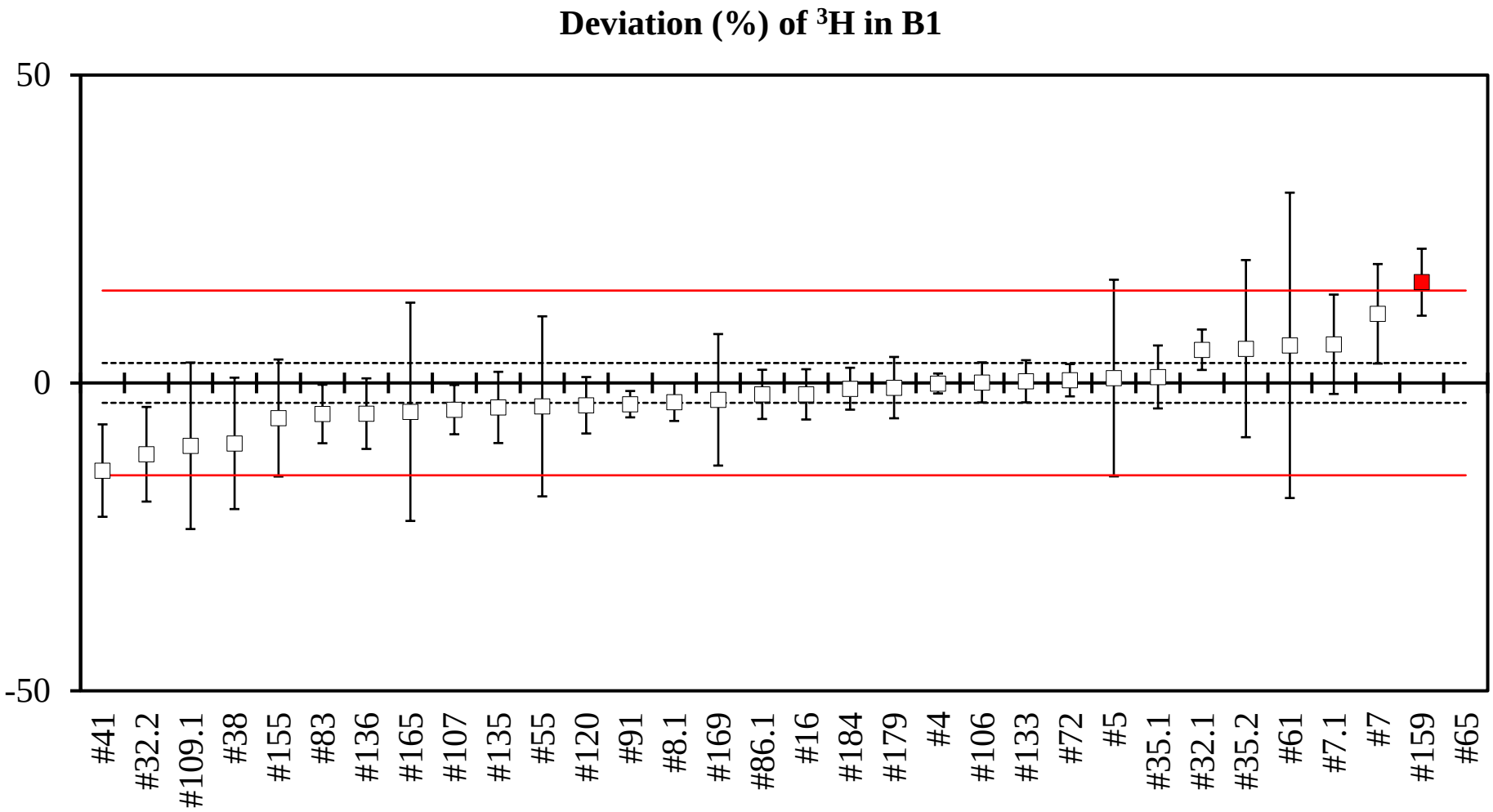
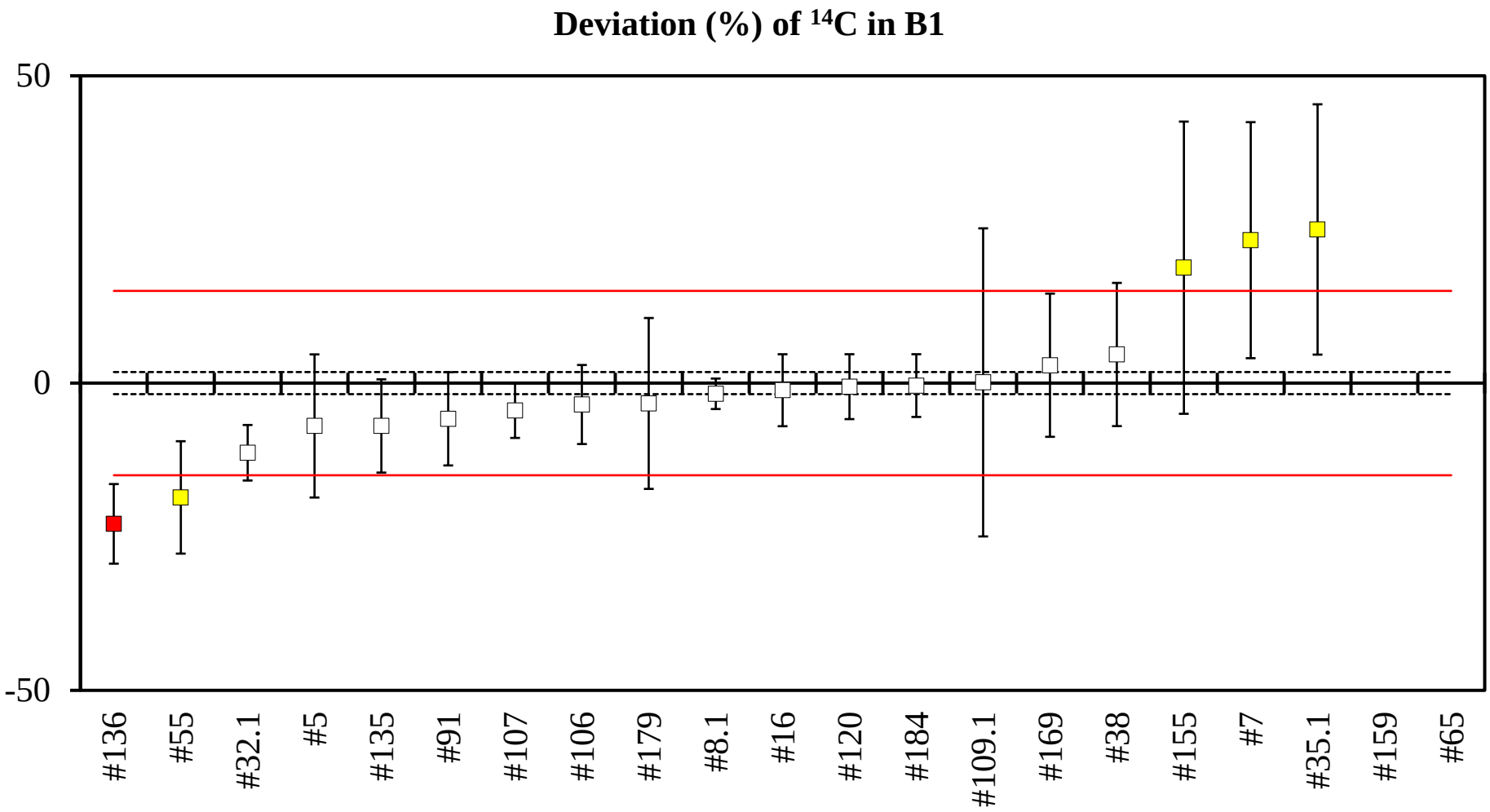
0
-50
#38
#1
#8.1
#7
#86.1
#91

6. Beta One (B1) Deviation Plots


Deviation (%) of 3H in B1
50
0
-50
#41
#32.2
#109.1
#38
#155
#83
#136
#165
#107
#135
#55
#120
#91
#8.1
#169
#86.1
#16
#184
#179
#4
#106
#133
#72
#5
#35.1
#32.1
#35.2
#61
#7.1
#7
#159
#65


Deviation (%) of 14C in B1
50
0
-50
#136
#55
#32.1
#5
#135
#91
#107
#106
#179
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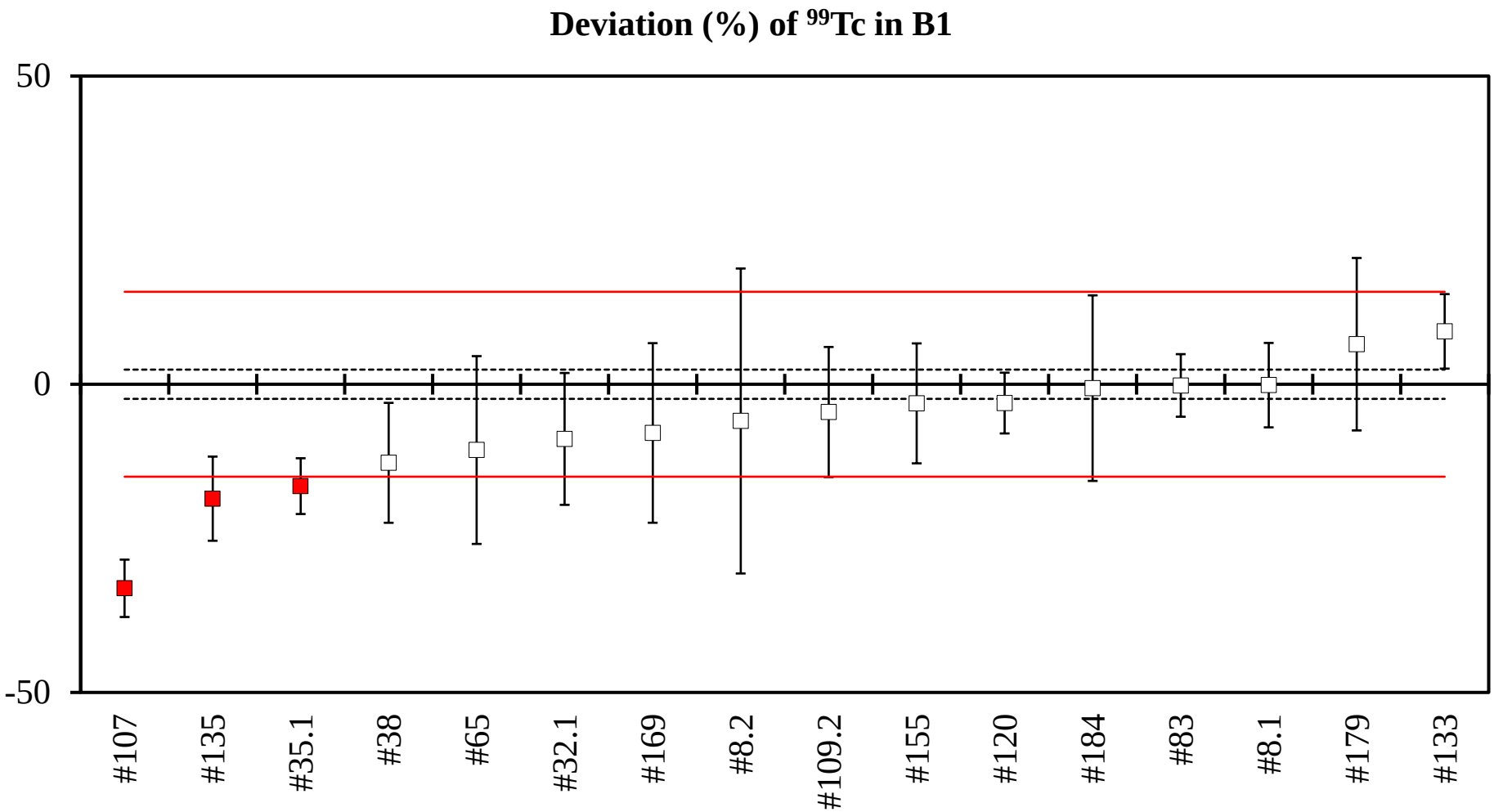
#184
#109.1
#169
#38
#155
#7
#35.1
#159
#65


Deviation (%) of 99Tc in B1
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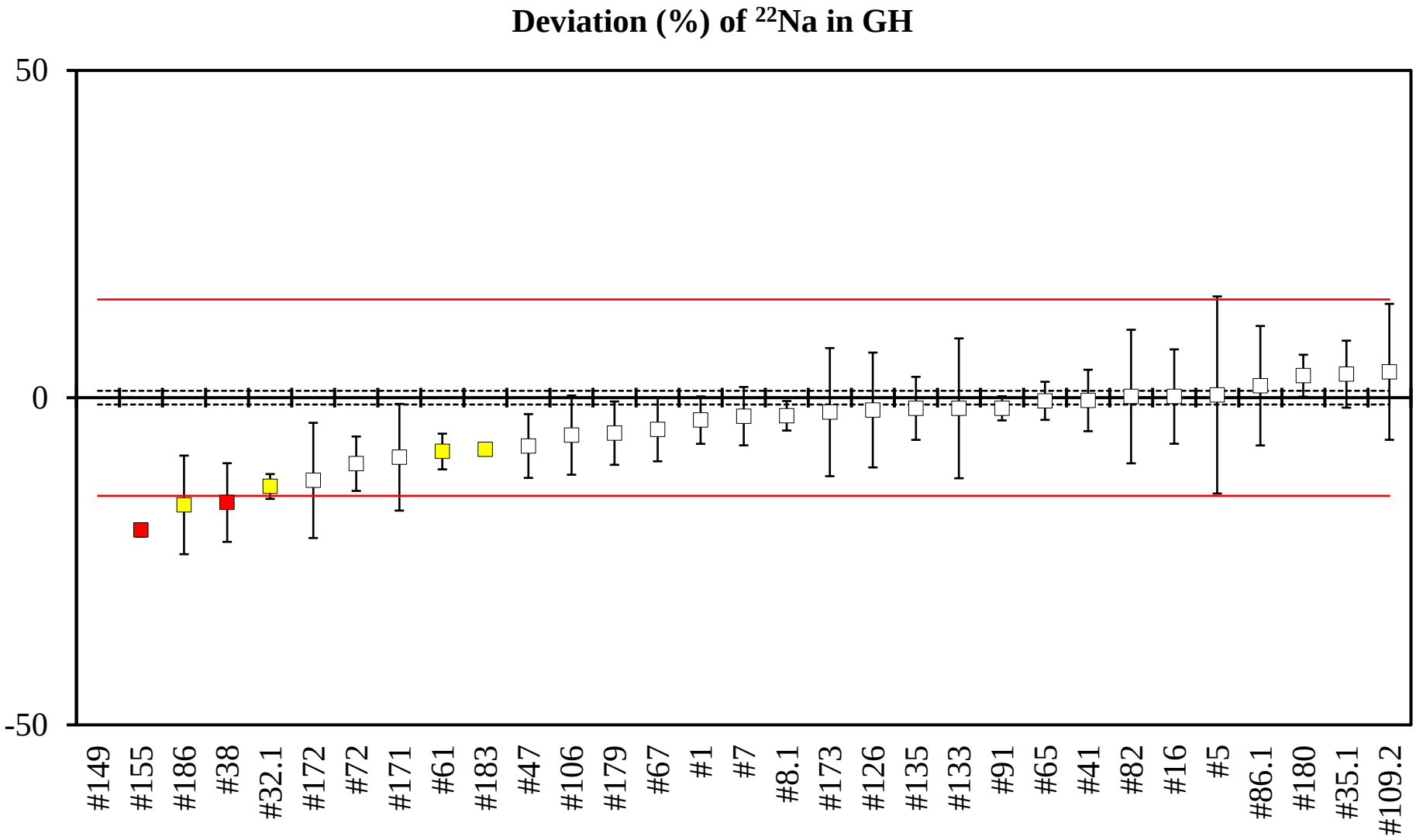
-50
#107
#135
#35.1
#38
#65
#32.1
#169
#8.2
#109.2
#155
#120
#184
#83
#8.1
#179
#133

7. Gamma High (GH) Deviation Plots


Deviation (%) of 22Na in GH
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0
-50
#149
#155
#186
#38
#32.1
#172
#72
#171
#61
#183
#47
#106
#179
#67
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#7
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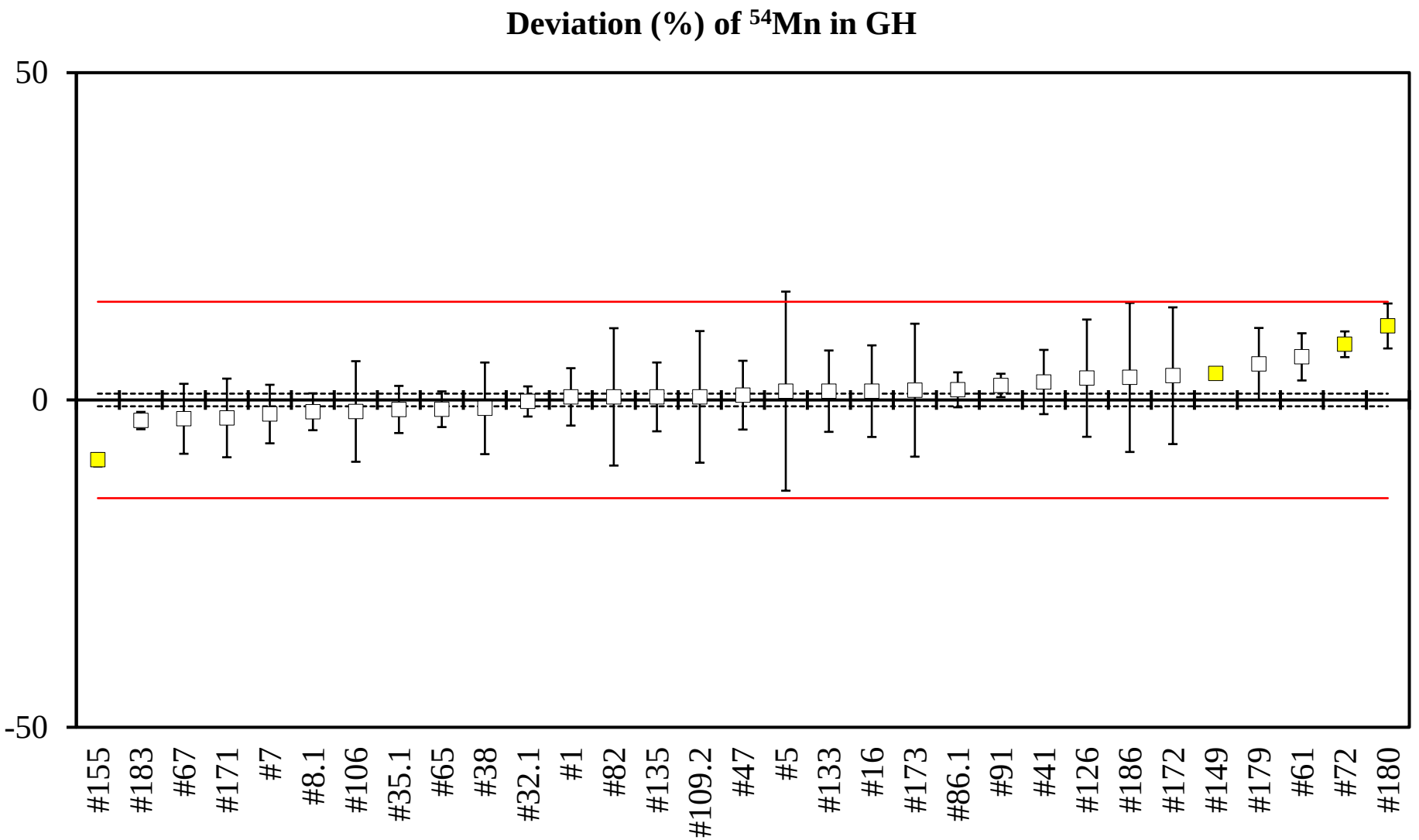
#16
#5
#86.1
#180
#35.1
#109.2


Deviation (%) of 54Mn in GH
50
0
-50
#155
#183
#67
#171
#7
#8.1
#106
#35.1
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#47
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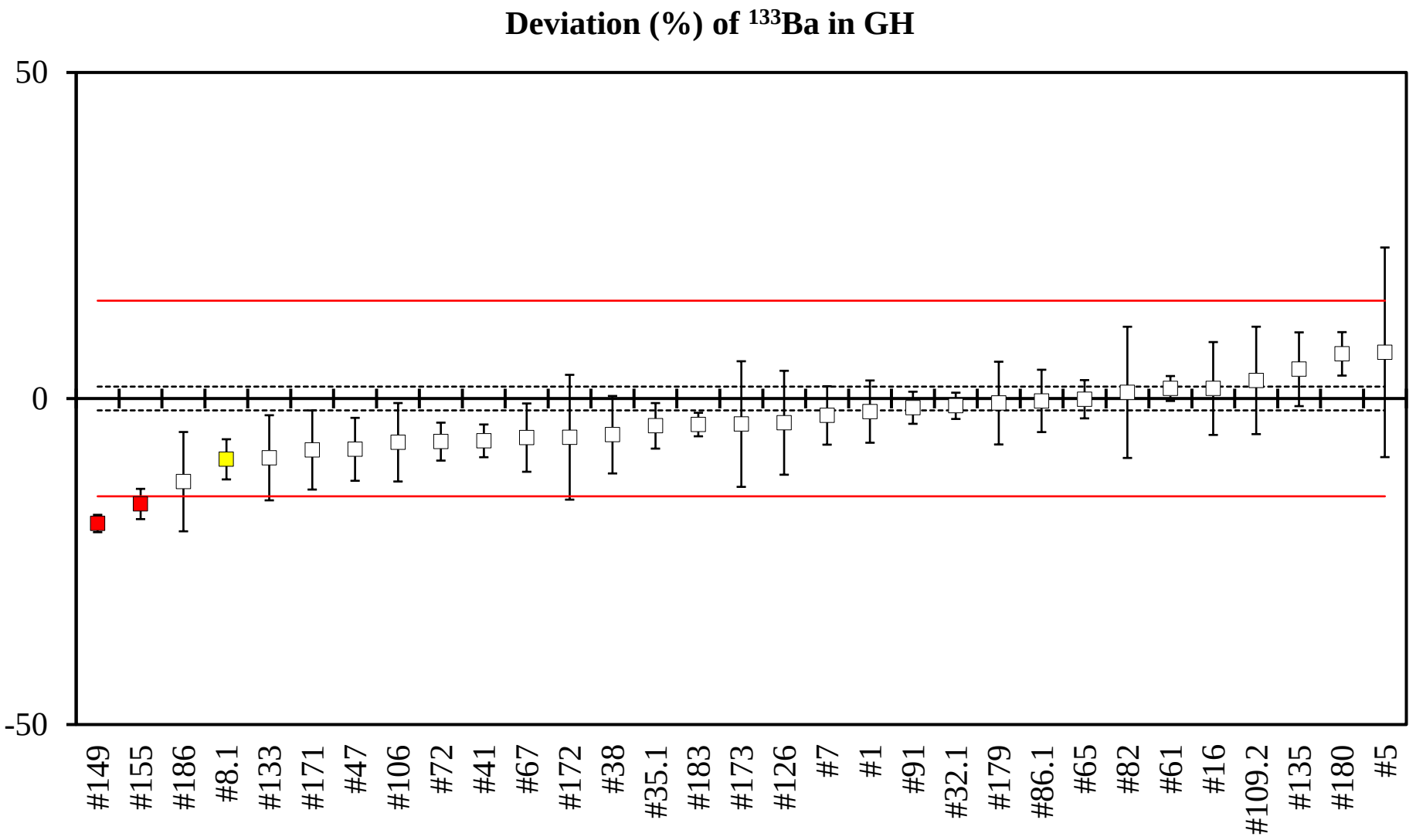
#91
#41
#126
#186
#172
#149
#179
#61
#72
#180


Deviation (%) of 133Ba in GH
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0
-50
#149
#155
#186
#8.1
#133
#171
#47
#106
#72
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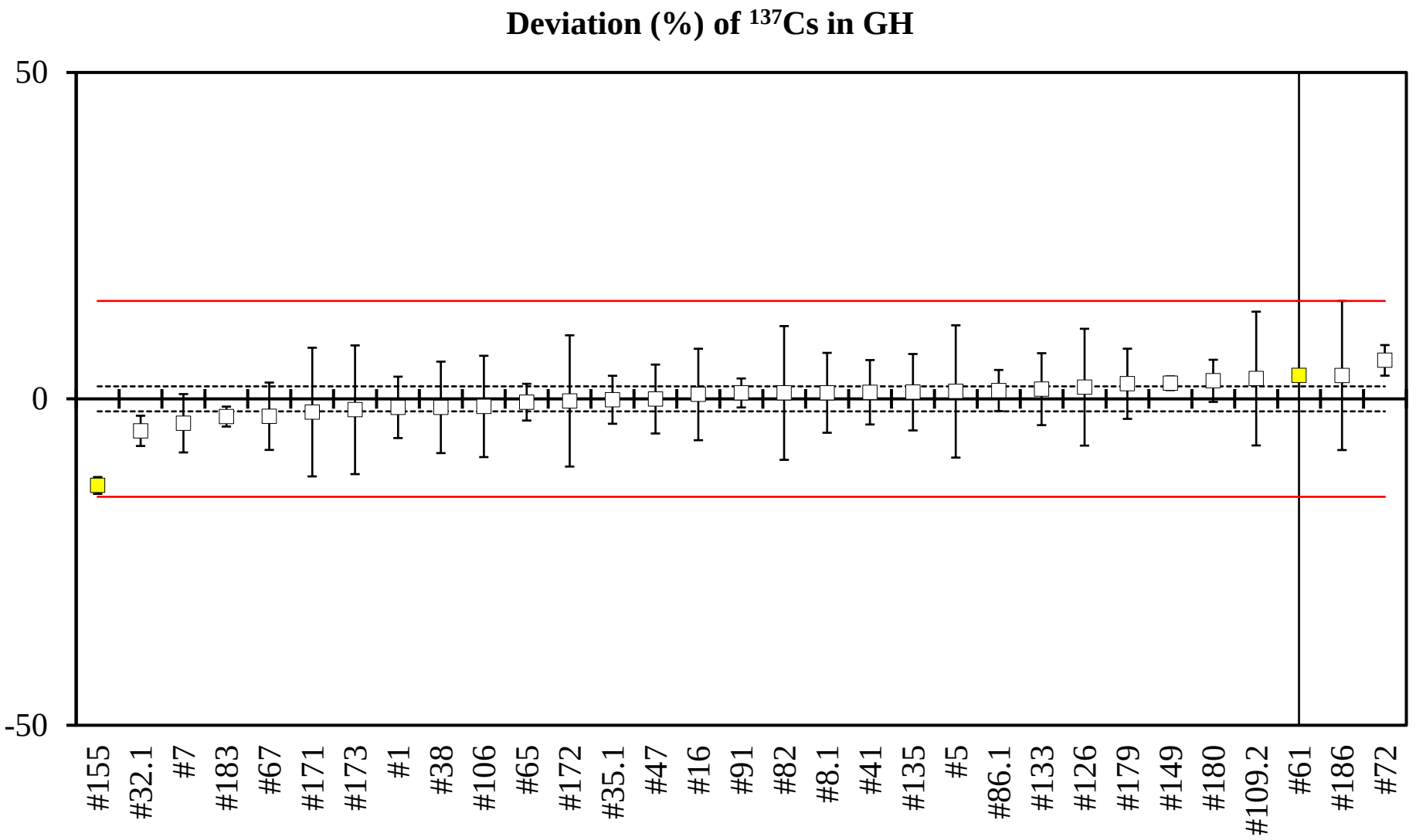
#109.2
#135
#180
#5


Deviation (%) of 137Cs in GH
50
0
-50
#155
#32.1
#7
#183
#67
#171
#173
#1
#38
#106
#65
#172
#35.1
#47
#16
#91
#82
#8.1
#41
#135
#5
#86.1
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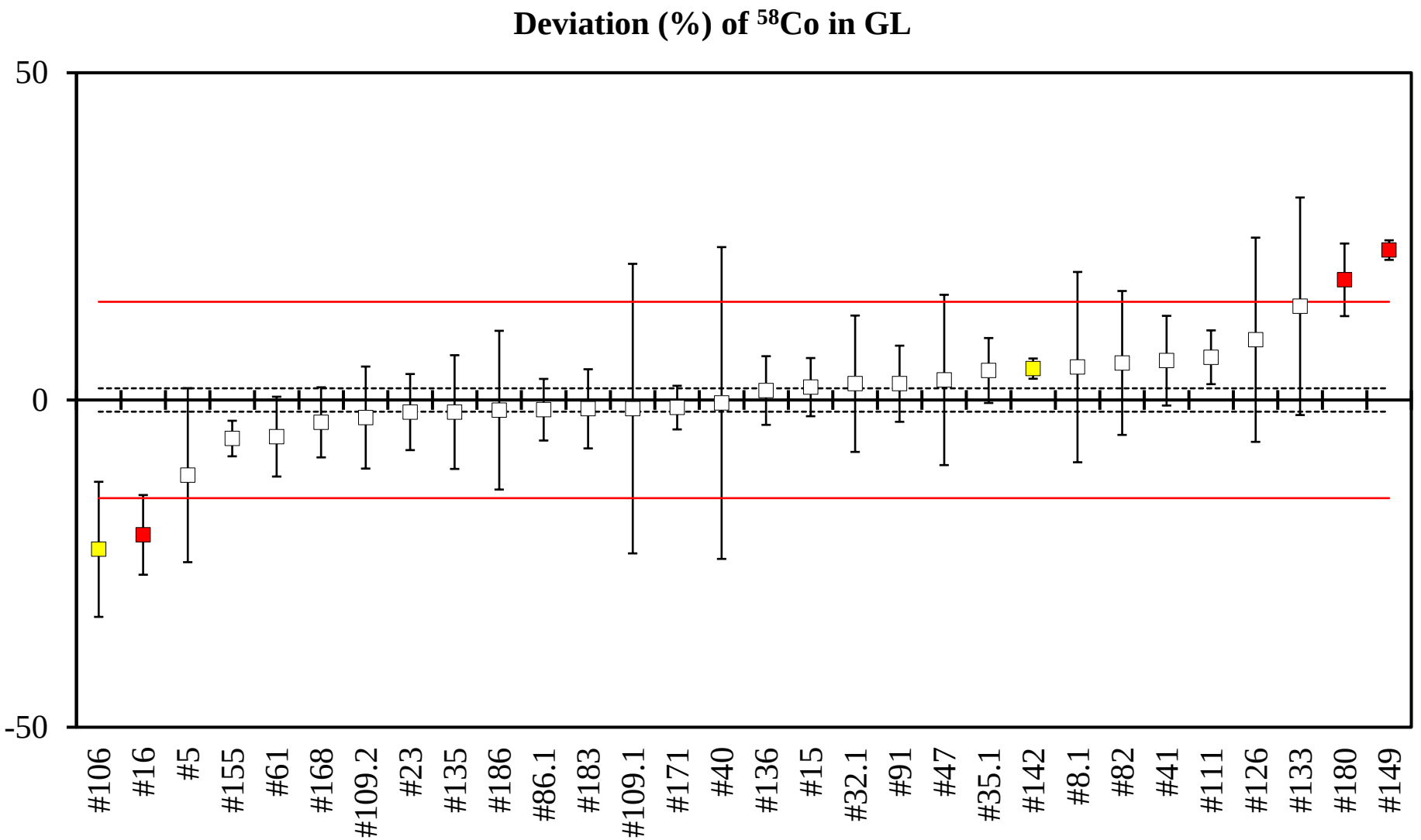
#179
#149
#180
#109.2
#61
#186
#72

8. Gamma Low (GL) Deviation Plots


Deviation (%) of 58Co in GL
50
0
-50
#106
#16
#5
#155
#61
#168
#109.2
#23
#135
#186
#86.1
#183
#109.1
#171
#40
#136
#15
#32.1
#91
#47
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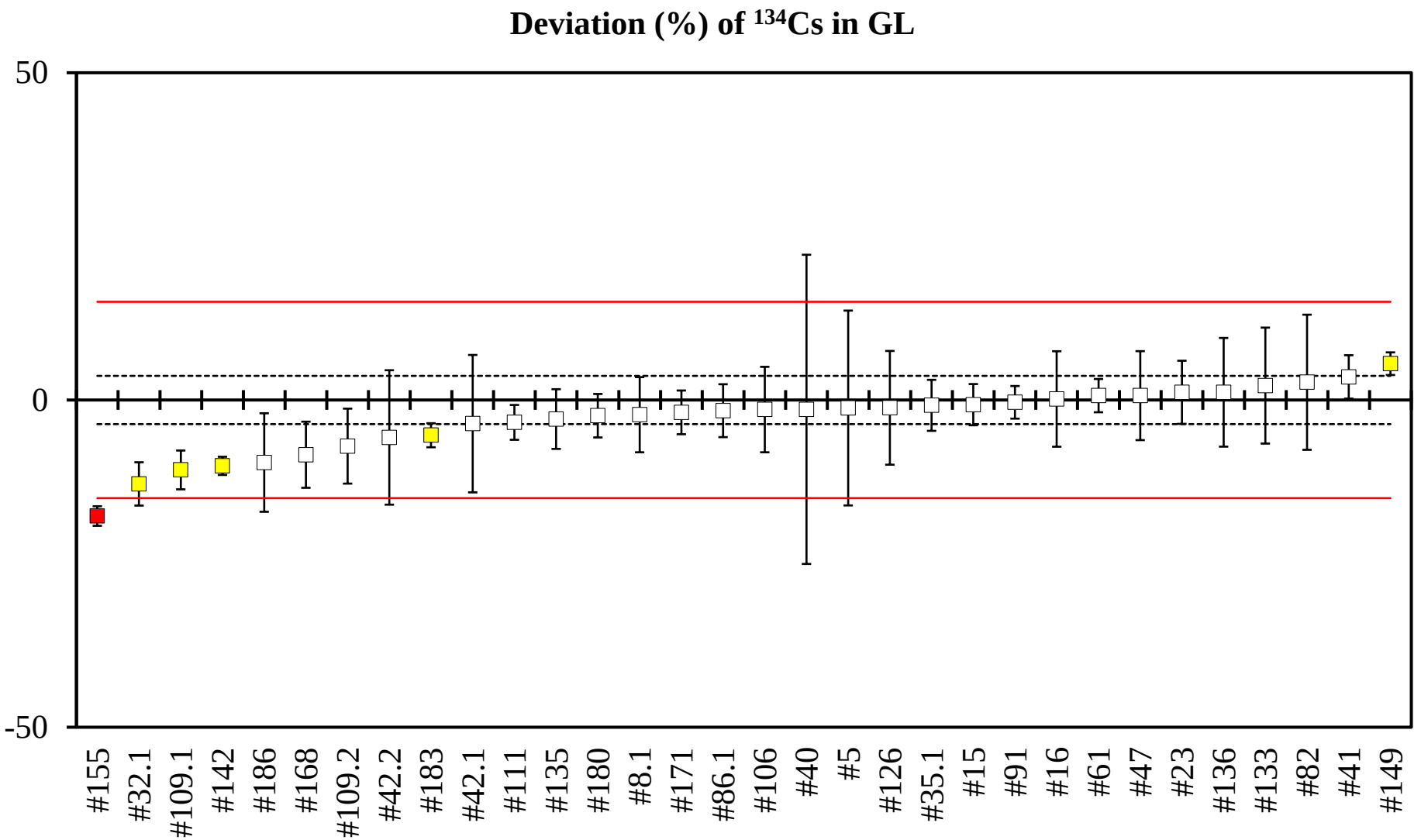
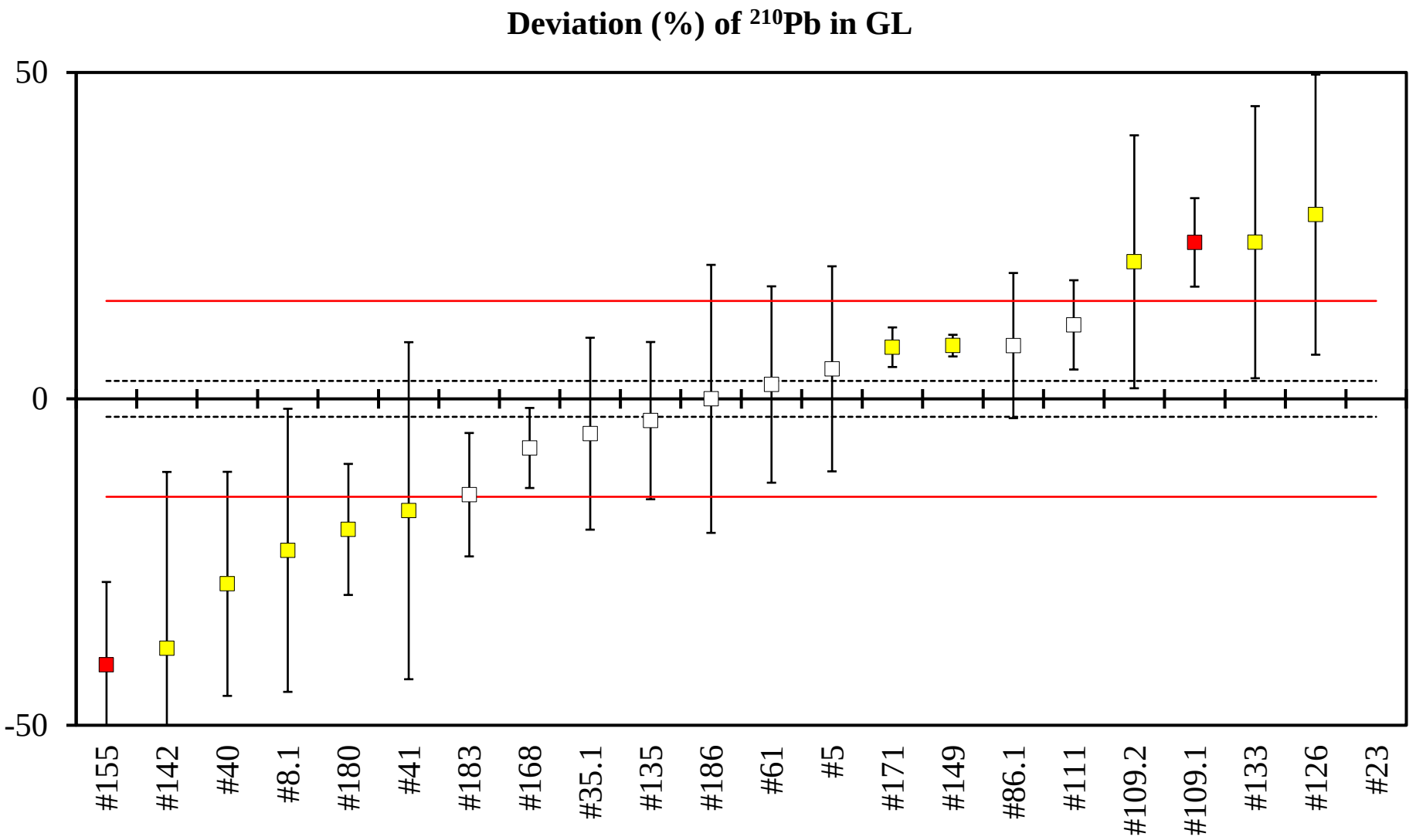
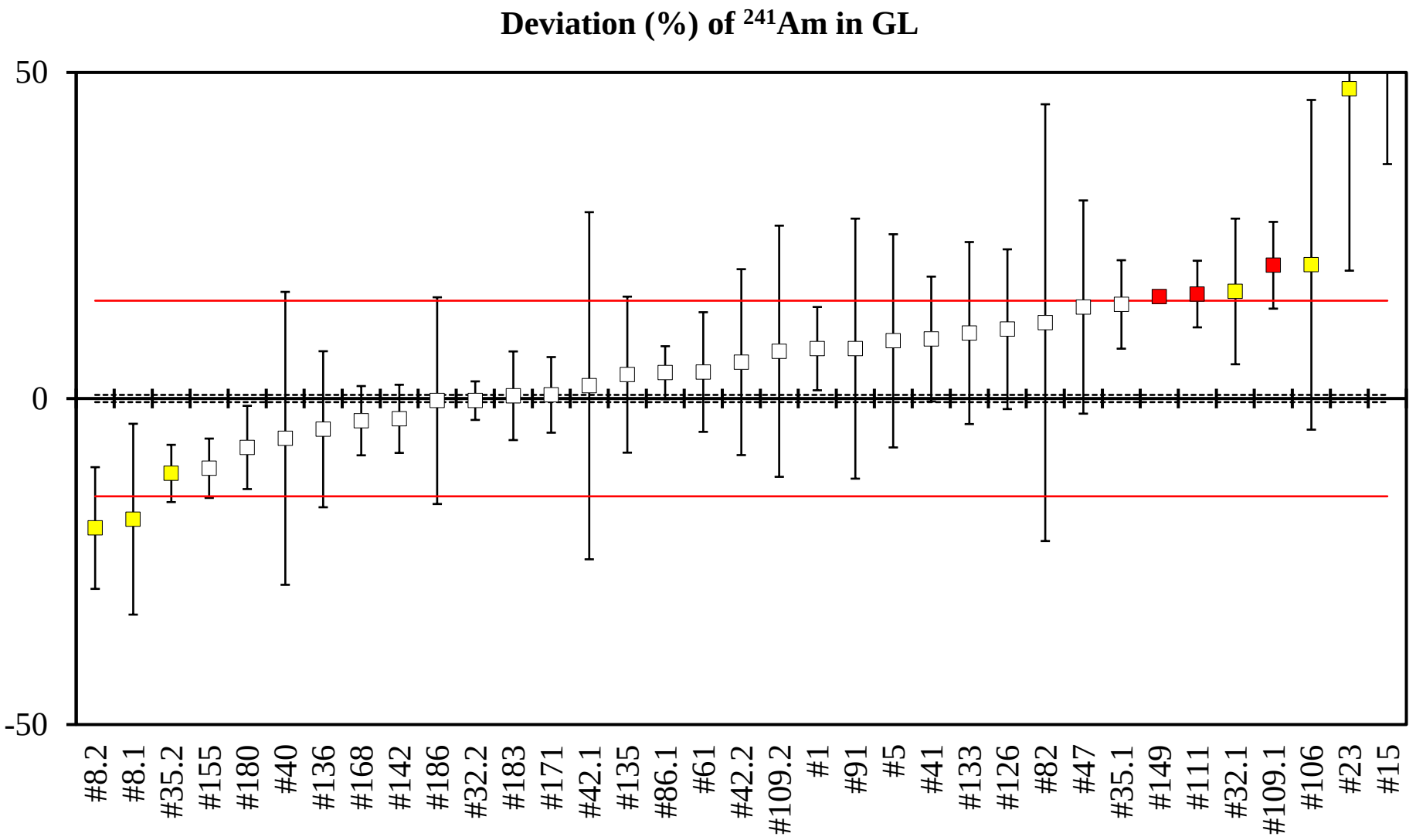
#8.1
#82
#41
#111
#126
#133
#180
#149


Deviation (%) of 134Cs in GL
50
0
-50
#155
#32.1
#109.1
#142
#186
#168
#109.2
#42.2
#183
#42.1
#111
#135
#180
#8.1
#171
#86.1
#106
#40
#5
#126
#35.1
#15
#91
#16
#61
#47
#23
#136
#133
#82
#41
#149

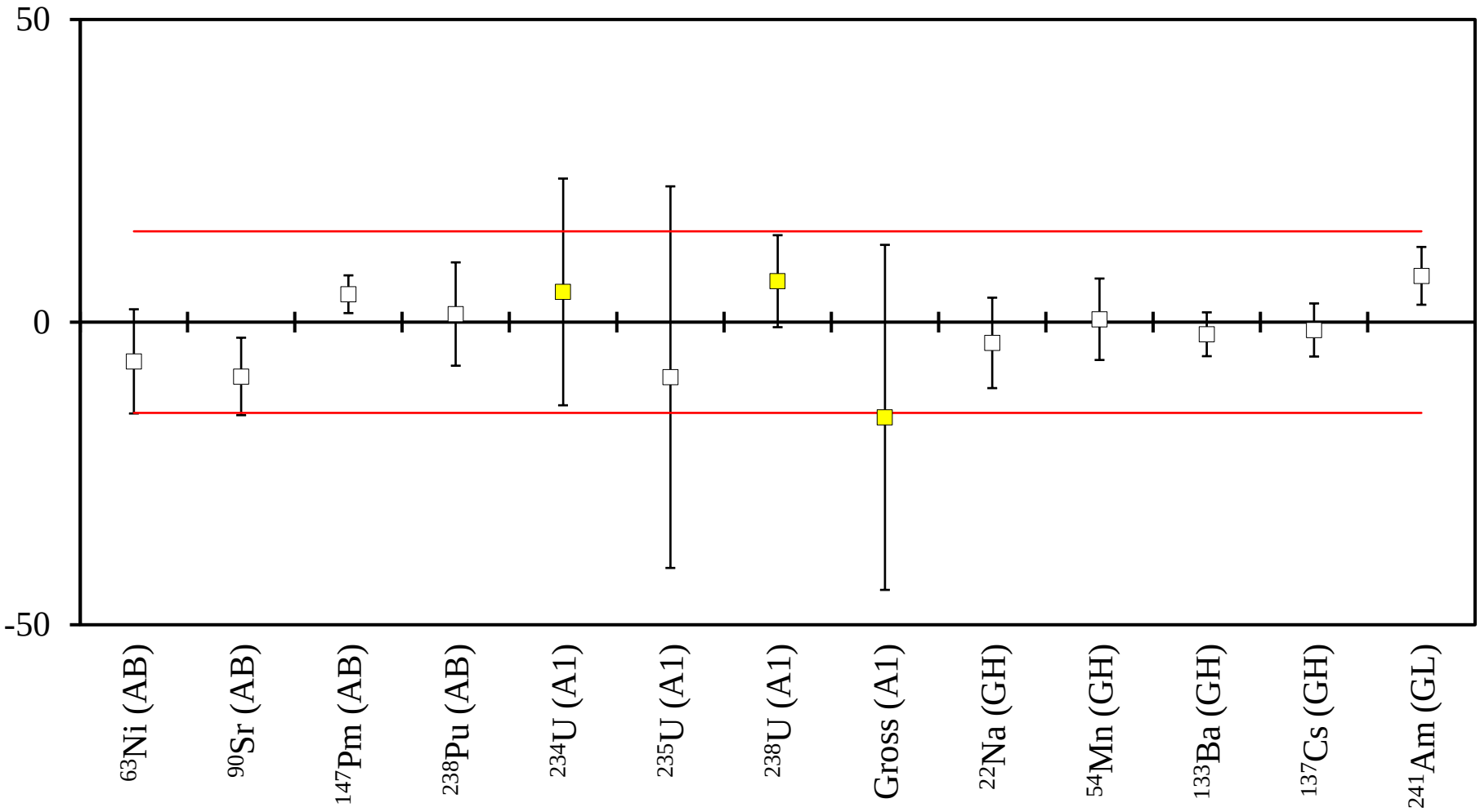

Deviation (%) of 210Pb in GL
50
0
-50
#155
#142
#40
#8.1
#180
#41
#183
#168
#35.1
#135
#186
#61
#5
#171
#149
#86.1
#111
#109.2
#109.1
#133
#126
#23


Deviation (%) of 241Am in GL
50
0
-50
#8.2
#8.1
#35.2
#155
#180
#40
#136
#168
#142
#186
#32.2
#183
#171
#42.1
#135
#86.1
#61
#42.2
#109.2
#1
#91
#5
#41
#133
#126
#82
#47
#35.1
#149
#111
#32.1
#109.1
#106
#23
#15

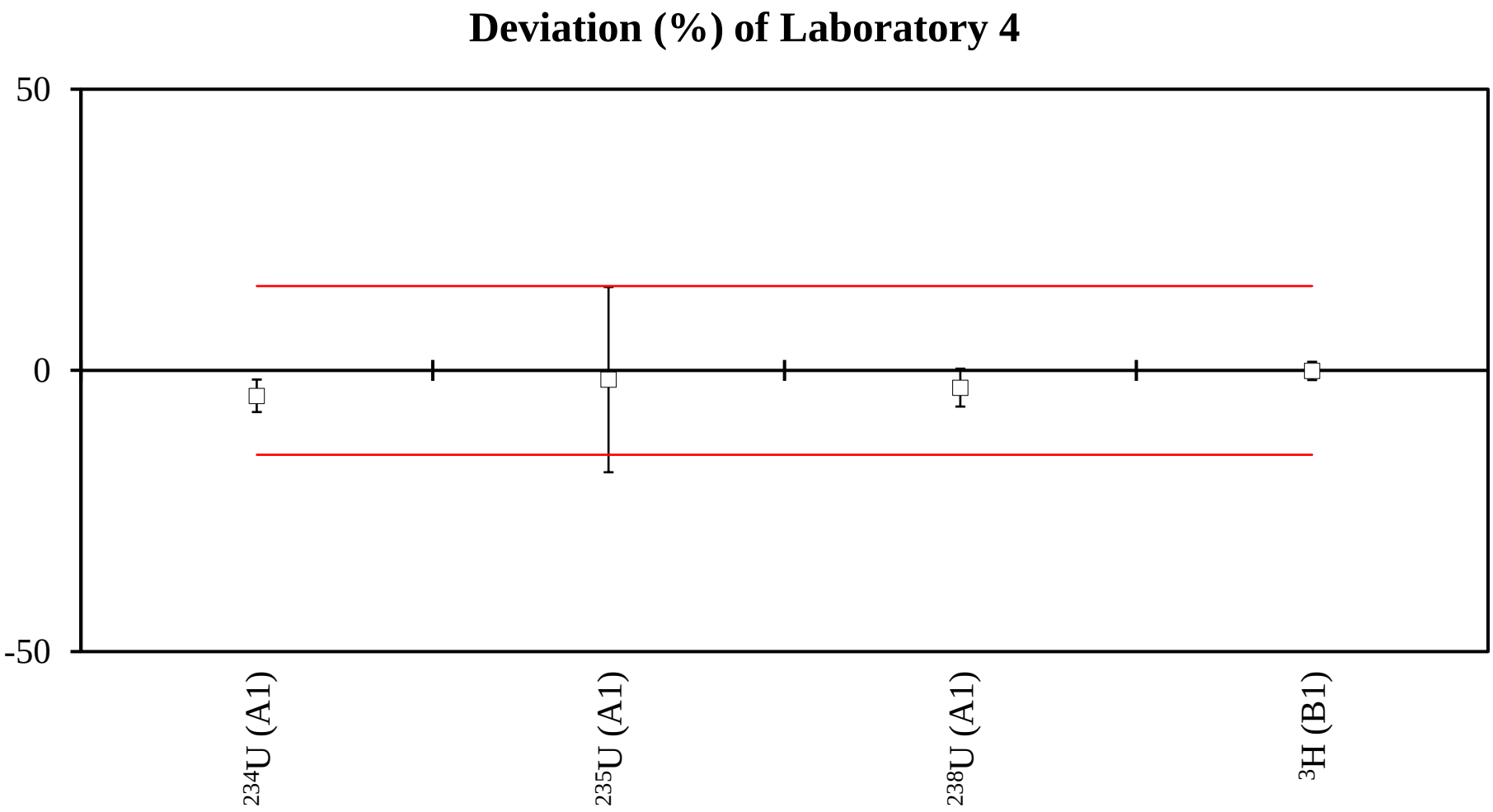
10. Deviation Plots and Tabulated Results Arranged by Lab Number

NOTE:

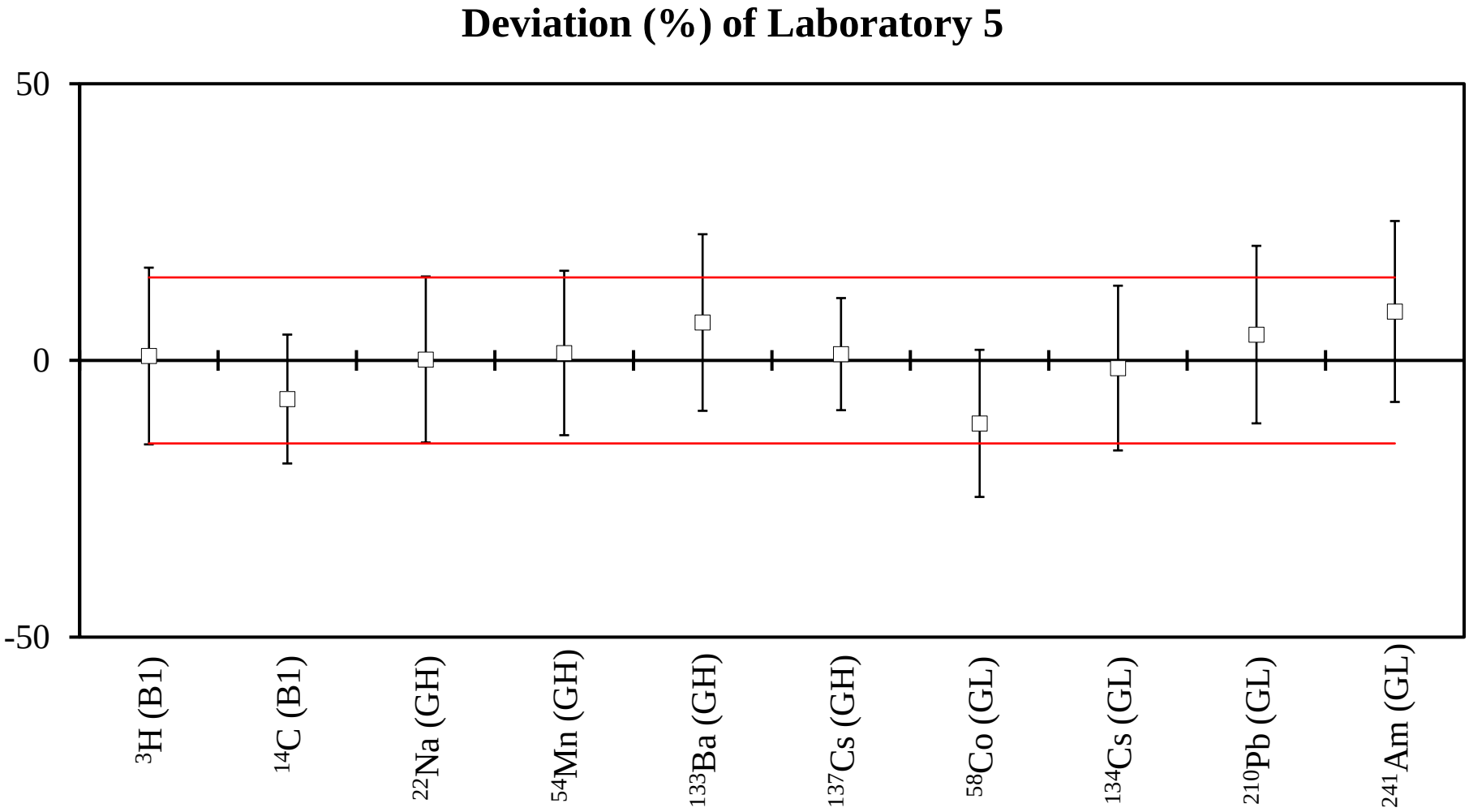
1. Data are quoted rounded, at $k = 1$ (standard uncertainty). Data analysis was carried out on data as reported (i.e. before rounding). Uncertainties have been rounded to two significant figures.
2. Units of the Assigned Values and the reported results are as follows:
    a. AB – Bq g^{-1}
    b. A1 – Bq kg^{-1}
    c. B1 – Bq g^{-1}
    d. GH – Bq g^{-1}
    e. GL – Bq kg^{-1}


Deviation (%) of Laboratory 1
50
0
-50
63Ni (AB)
90Sr (AB)
147Pm (AB)
238Pu (AB)
234U (A1)
235U (A1)
238U (A1)
Gross (A1)
22Na (GH)
54Mn (GH)
133Ba (GH)
137Cs (GH)
241Am (GL)

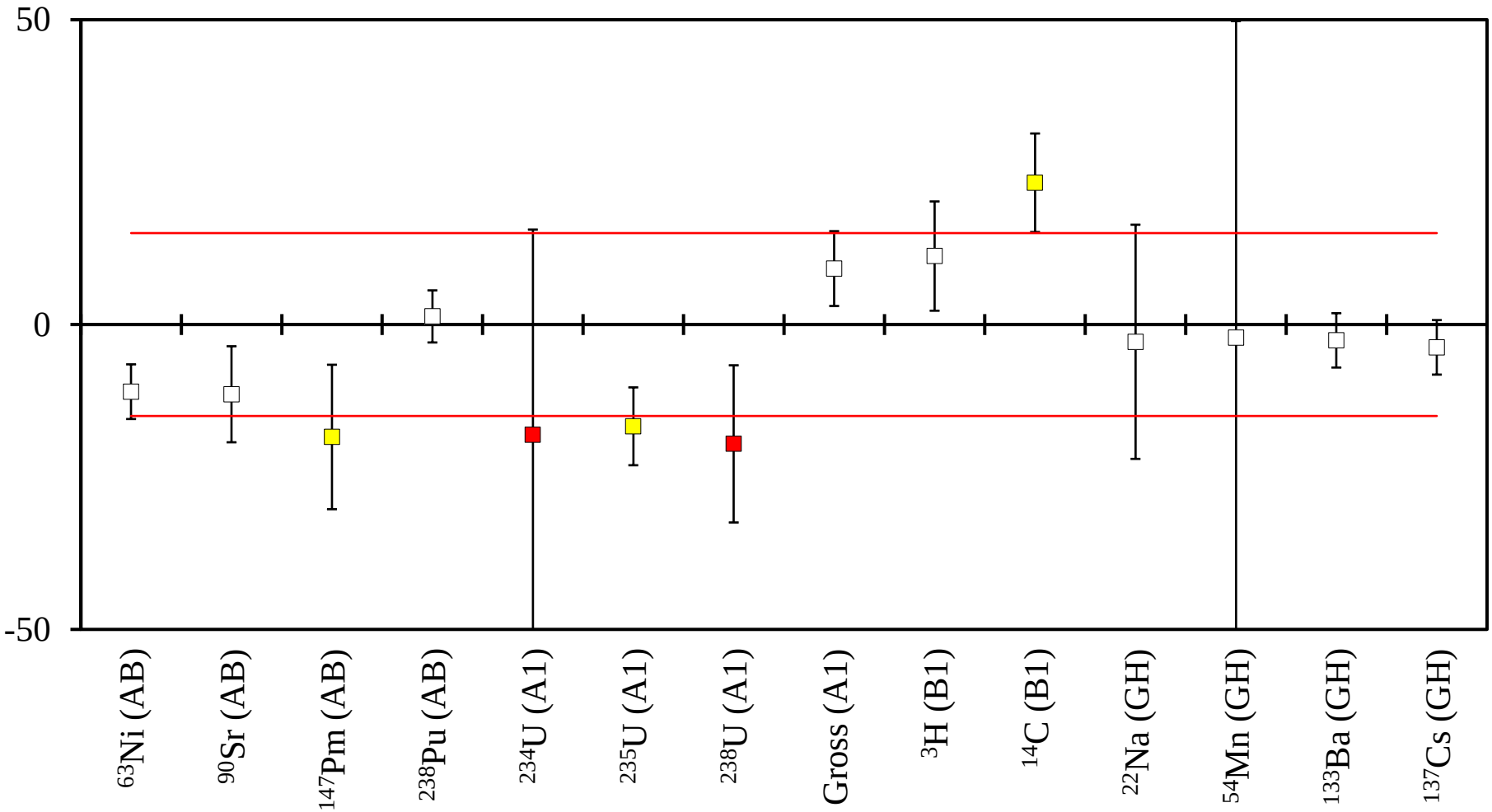
Radionuclide	Laboratory 1	NPL Assigned Value	Deviation (%)	Zeta	Z Score
^{63}Ni (AB)	1.86 ± 0.17	1.989 ± 0.022	-6.5	-0.75	-1.11
^{90}Sr (AB)	1.85 ± 0.13	2.0324 ± 0.0054	-9.0	-1.40	-1.54
^{147}Pm (AB)	17.70 ± 0.50	16.92 ± 0.16	4.6	1.49	0.79
^{238}Pu (AB)	9.50 ± 0.80	9.375 ± 0.021	1.3	0.16	0.23
Gross beta (AB)	9.7 ± 1.0	-	-	-	-
^{234}U (A1)	20.0 ± 6.0	19.05 ± 0.24	5.0	0.16	0.86
^{235}U (A1)	0.610 ± 0.050	0.671 ± 0.011	-9.1	-1.19	-1.56
^{238}U (A1)	15.0 ± 4.0	14.05 ± 0.18	6.8	0.24	1.16
Gross alpha (A1)	25.7 ± 1.7	30.5 ± 1.8	-15.7	-1.94	-2.70
Gross beta (B1)	0.099 ± 0.018	-	-	-	-
^{22}Na (GH)	16.1 ± 0.6	16.672 ± 0.068	-3.4	-0.95	-0.59
^{54}Mn (GH)	11.50 ± 0.50	11.446 ± 0.043	0.5	0.11	0.08
^{133}Ba (GH)	16.60 ± 0.80	16.94 ± 0.12	-2.0	-0.42	-0.34
^{137}Cs (GH)	8.50 ± 0.40	8.612 ± 0.064	-1.3	-0.28	-0.22
^{241}Am (GL)	2.70 ± 0.16	2.5082 ± 0.0054	7.6	1.20	1.31


Deviation (%) of Laboratory 4
50
0
-50
234U (A1)
235U (A1)
238U (A1)
3H (B1)

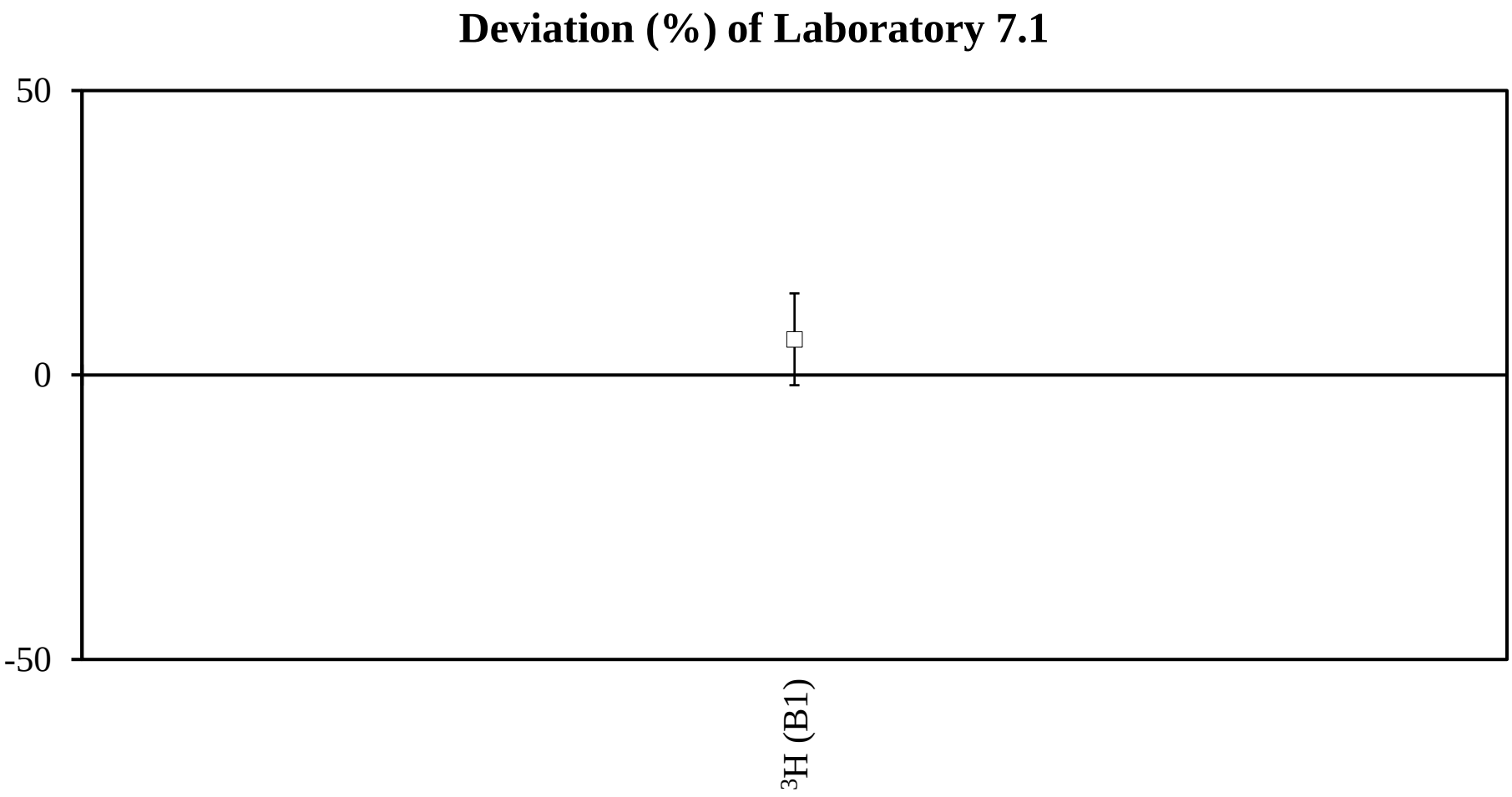
Radionuclide	Laboratory 4	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{234}U (A1)	18.19 ± 0.50	19.05 ± 0.24	-4.5	-1.55	-0.78
^{235}U (A1)	0.66 ± 0.11	0.671 ± 0.011	-1.6	-0.10	-0.28
^{238}U (A1)	13.62 ± 0.44	14.05 ± 0.18	-3.1	-0.90	-0.53
^{3}H (B1)	0.5650 ± 0.0058	0.5655 ± 0.0071	-0.1	-0.05	-0.02


Deviation (%) of Laboratory 5
50
0
-50
3H (B1)
14C (B1)
22Na (GH)
54Mn (GH)
133Ba (GH)
137Cs (GH)
58Co (GL)
134Cs (GL)
210Pb (GL)
241Am (GL)

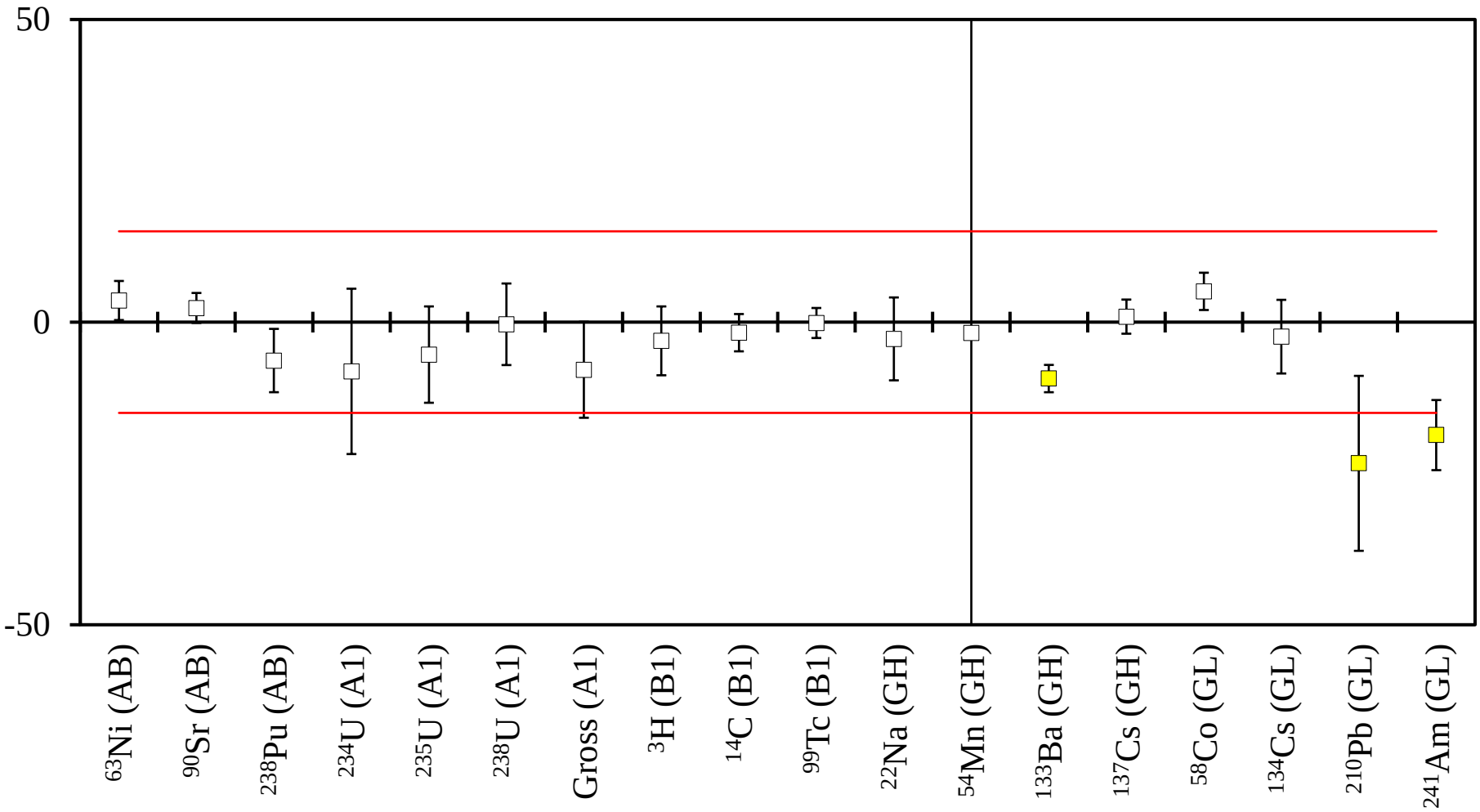
Radionuclide	Laboratory 5	NPL Assigned Value	Deviation (%)	Zeta	Z Score
^{3}H (B1)	0.57 ± 0.09	0.5655 ± 0.0071	0.8	0.05	0.14
^{14}C (B1)	0.160 ± 0.020	0.1720 ± 0.0012	-7.0	-0.60	-1.20
^{22}Na (GH)	16.7 ± 2.5	16.672 ± 0.068	0.2	0.01	0.03
^{54}Mn (GH)	11.6 ± 1.7	11.446 ± 0.043	1.3	0.09	0.23
^{133}Ba (GH)	18.1 ± 2.7	16.94 ± 0.12	6.8	0.43	1.18
^{137}Cs (GH)	8.71 ± 0.87	8.612 ± 0.064	1.1	0.11	0.20
^{58}Co (GL)	30.7 ± 4.6	34.64 ± 0.24	-11.4	-0.86	-1.95
^{134}Cs (GL)	19.3 ± 2.9	19.57 ± 0.28	-1.4	-0.09	-0.24
^{210}Pb (GL)	15.7 ± 2.4	15.00 ± 0.16	4.7	0.29	0.80
^{241}Am (GL)	2.73 ± 0.41	2.5082 ± 0.0054	8.8	0.54	1.52


Deviation (%) of Laboratory 7
50
0
-50
63Ni (AB)
90Sr (AB)
147Pm (AB)
238Pu (AB)
234U (A1)
235U (A1)
238U (A1)
Gross (A1)
3H (B1)
14C (B1)
22Na (GH)
54Mn (GH)
133Ba (GH)
137Cs (GH)

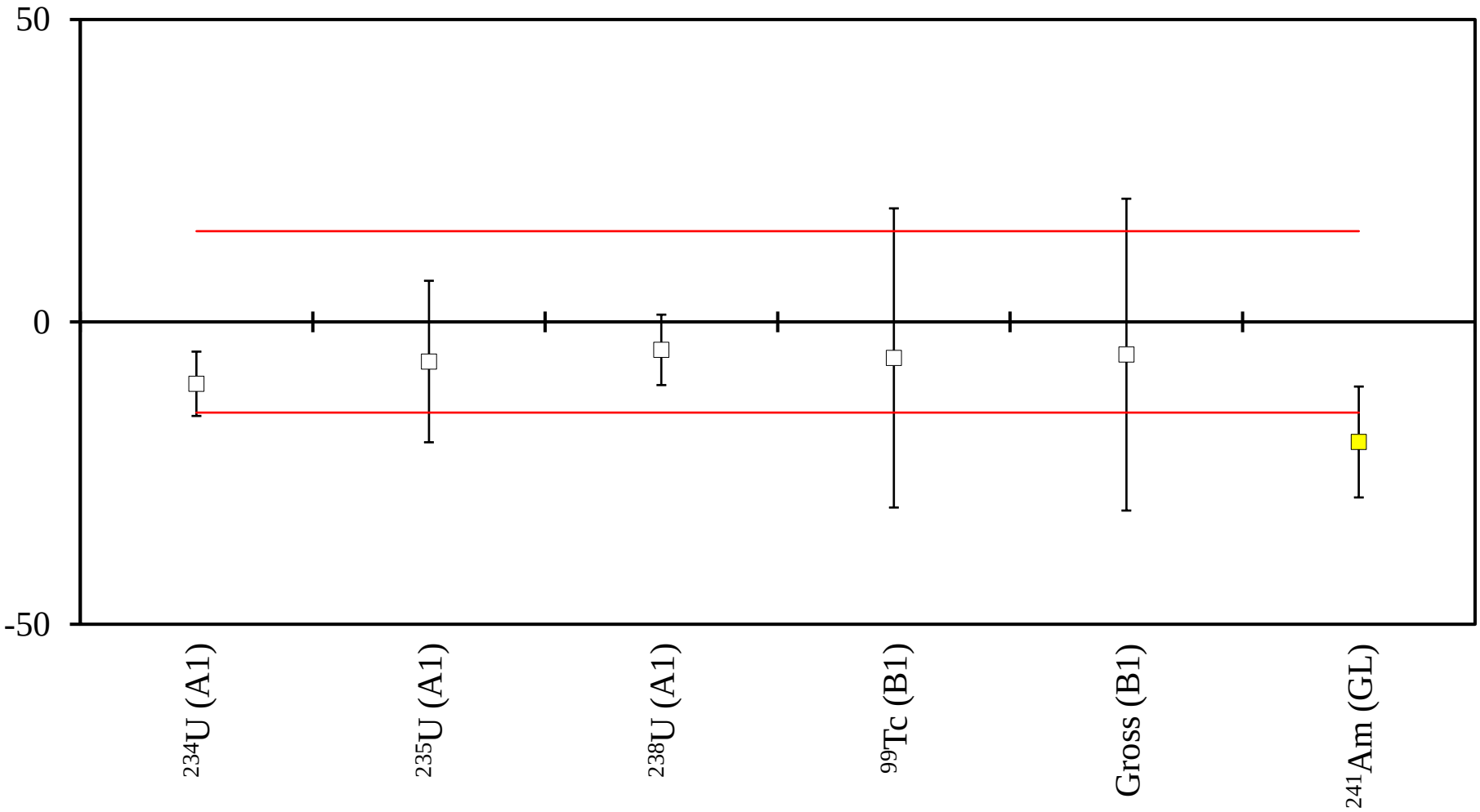
Radionuclide	Laboratory 7	NPL Assigned Value	Deviation (%)	Zeta	Z Score
^{63}Ni (AB)	1.770 ± 0.087	1.989 ± 0.022	-11.0	-2.44	-1.89
^{90}Sr (AB)	1.80 ± 0.16	2.0324 ± 0.0054	-11.4	-1.45	-1.96
^{147}Pm (AB)	13.8 ± 2.0	16.92 ± 0.16	-18.4	-1.56	-3.17
^{238}Pu (AB)	9.50 ± 0.40	9.375 ± 0.021	1.3	0.31	0.23
Gross beta (AB)	18.5 ± 1.4	-	-	-	-
^{234}U (A1)	15.6 ± 1.2	19.05 ± 0.24	-18.1	-2.82	-3.11
^{235}U (A1)	0.559 ± 0.086	0.671 ± 0.011	-16.7	-1.29	-2.87
^{238}U (A1)	11.30 ± 0.85	14.05 ± 0.18	-19.6	-3.17	-3.36
Gross alpha (A1)	33.3 ± 1.9	30.5 ± 1.8	9.2	1.07	1.58
^{3}H (B1)	0.629 ± 0.045	0.5655 ± 0.0071	11.2	1.39	1.93
^{14}C (B1)	0.212 ± 0.033	0.1720 ± 0.0012	23.3	1.21	3.99
Gross beta (B1)	0.884 ± 0.069	-	-	-	-
^{22}Na (GH)	16.20 ± 0.74	16.672 ± 0.068	-2.8	-0.64	-0.49
^{54}Mn (GH)	11.20 ± 0.51	11.446 ± 0.043	-2.1	-0.48	-0.37
^{133}Ba (GH)	16.50 ± 0.75	16.94 ± 0.12	-2.6	-0.58	-0.45
^{137}Cs (GH)	8.29 ± 0.38	8.612 ± 0.064	-3.7	-0.84	-0.64


Deviation (%) of Laboratory 7.1
50
0
-50
^{3}H (B1)

Radionuclide	Laboratory 7.1	NPL Assigned Value	Deviation (%)	Zeta	Z Score
^{3}H (B1)	0.601 ± 0.045	0.5655 ± 0.0071	6.3	0.78	1.08


Deviation (%) of Laboratory 8.1
50
0
-50
63Ni (AB)
90Sr (AB)
238Pu (AB)
234U (A1)
235U (A1)
238U (A1)
Gross (A1)
3H (B1)
14C (B1)
99Tc (B1)
22Na (GH)
54Mn (GH)
133Ba (GH)
137Cs (GH)
58Co (GL)
134Cs (GL)
210Pb (GL)
241Am (GL)

Radionuclide	Laboratory 8.1	NPL Assigned Value	Deviation (%)	Zeta	Z Score
^{63}Ni (AB)	2.06 ± 0.06	1.989 ± 0.022	3.6	1.11	0.61
^{90}Sr (AB)	2.080 ± 0.050	2.0324 ± 0.0054	2.3	0.95	0.40
^{238}Pu (AB)	8.78 ± 0.49	9.375 ± 0.021	-6.3	-1.21	-1.09
Gross beta (AB)	8.110 ± 0.050	-	-	-	-
^{234}U (A1)	17.5 ± 1.5	19.05 ± 0.24	-8.1	-1.02	-1.40
^{235}U (A1)	0.635 ± 0.044	0.671 ± 0.011	-5.4	-0.79	-0.92
^{238}U (A1)	14.0 ± 1.1	14.05 ± 0.18	-0.4	-0.04	-0.06
Gross alpha (A1)	28.10 ± 0.51	30.5 ± 1.8	-7.9	-1.28	-1.35
^{3}H (B1)	0.548 ± 0.016	0.5655 ± 0.0071	-3.1	-1.00	-0.53
^{14}C (B1)	0.1690 ± 0.0041	0.1720 ± 0.0012	-1.7	-0.70	-0.30
^{99}Tc (B1)	0.206 ± 0.014	0.2063 ± 0.0019	-0.1	-0.02	-0.02
Gross beta (B1)	1.03 ± 0.03	-	-	-	-
^{22}Na (GH)	16.21 ± 0.37	16.672 ± 0.068	-2.8	-1.23	-0.48
^{54}Mn (GH)	11.24 ± 0.32	11.446 ± 0.043	-1.8	-0.64	-0.31
^{133}Ba (GH)	15.36 ± 0.51	16.94 ± 0.12	-9.3	-3.02	-1.60
^{137}Cs (GH)	8.69 ± 0.52	8.612 ± 0.064	0.9	0.15	0.16
^{58}Co (GL)	36.4 ± 5.0	34.64 ± 0.24	5.1	0.35	0.87
^{134}Cs (GL)	19.1 ± 1.1	19.57 ± 0.28	-2.4	-0.41	-0.41
^{210}Pb (GL)	11.5 ± 3.3	15.00 ± 0.16	-23.3	-1.06	-4.01
^{241}Am (GL)	2.04 ± 0.37	2.5082 ± 0.0054	-18.7	-1.27	-3.21


Deviation (%) of Laboratory 8.2
50
0
-50
234U (A1)
235U (A1)
238U (A1)
99Tc (B1)
Gross (B1)
241Am (GL)

Radionuclide	Laboratory 8.2	NPL Assigned Value	Deviation (%)	Zeta	Z Score
^{234}U (A1)	17.10 ± 0.99	19.05 ± 0.24	-10.2	-1.91	-1.76
^{235}U (A1)	0.627 ± 0.089	0.671 ± 0.011	-6.6	-0.49	-1.13
^{238}U (A1)	13.40 ± 0.80	14.05 ± 0.18	-4.6	-0.79	-0.79
^{99}Tc (B1)	0.194 ± 0.051	0.2063 ± 0.0019	-6.0	-0.24	-1.02
Gross beta (B1)	0.454 ± 0.014	-	-		-
^{241}Am (GL)	2.01 ± 0.23	2.5082 ± 0.0054	-19.9	-2.17	-3.41

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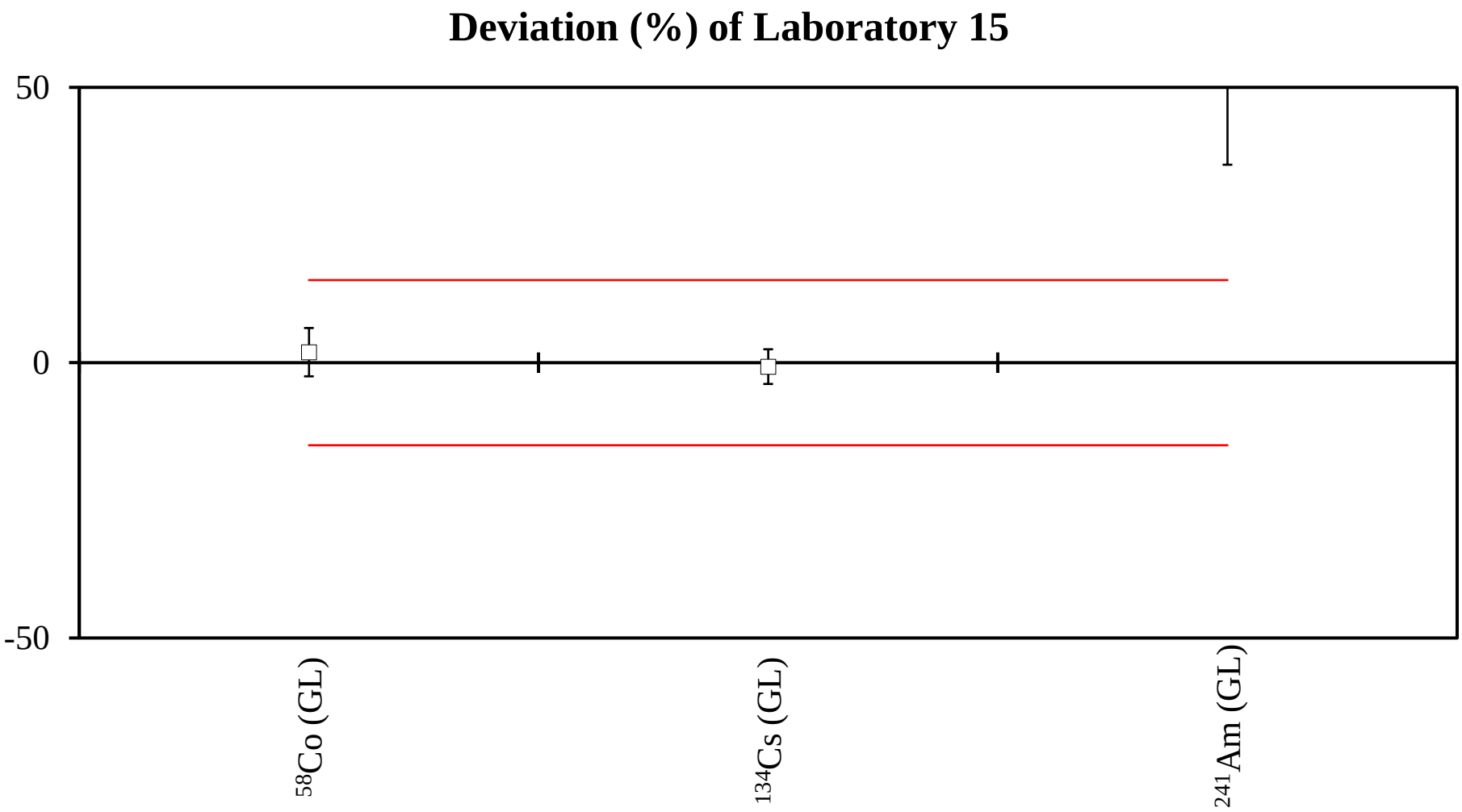
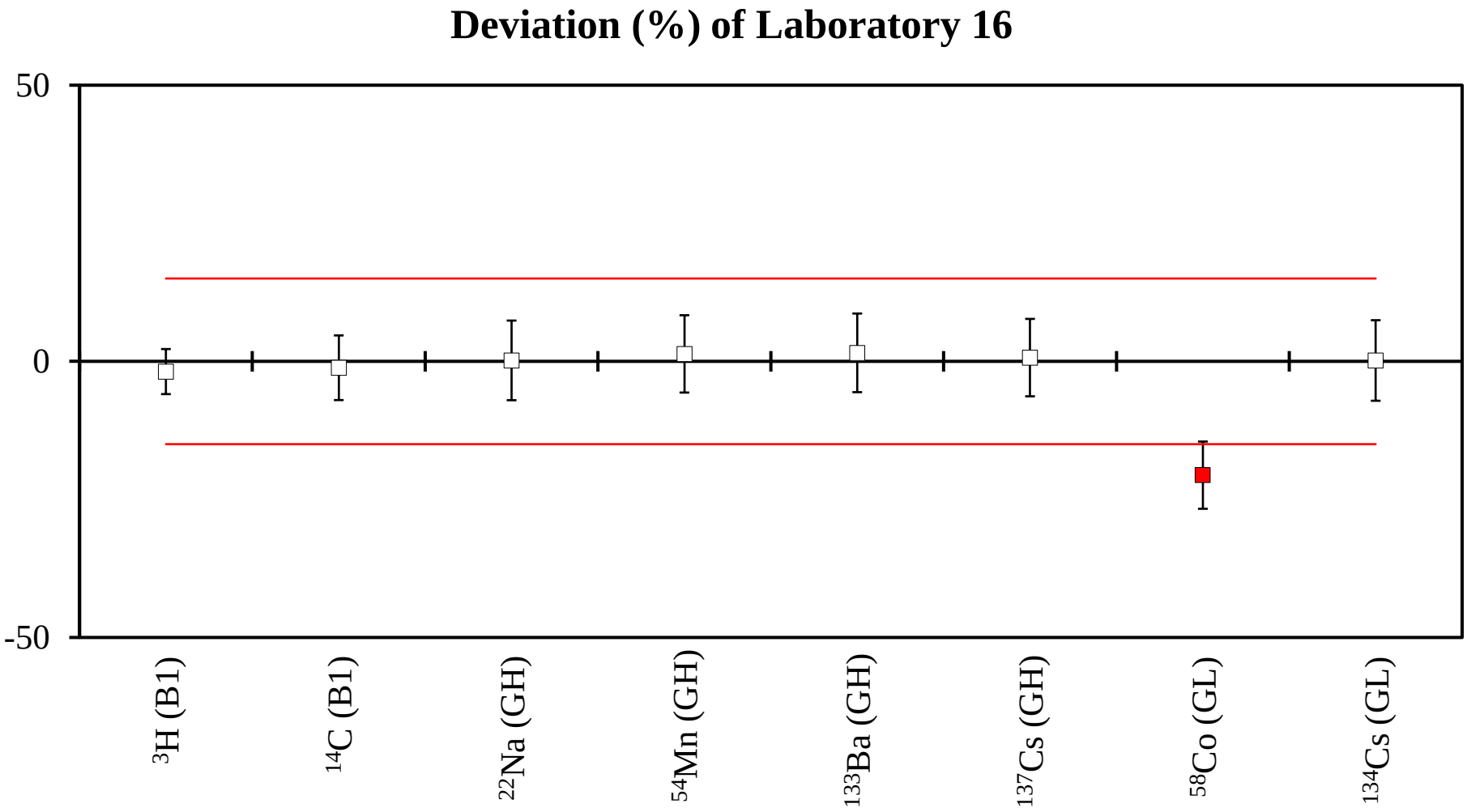
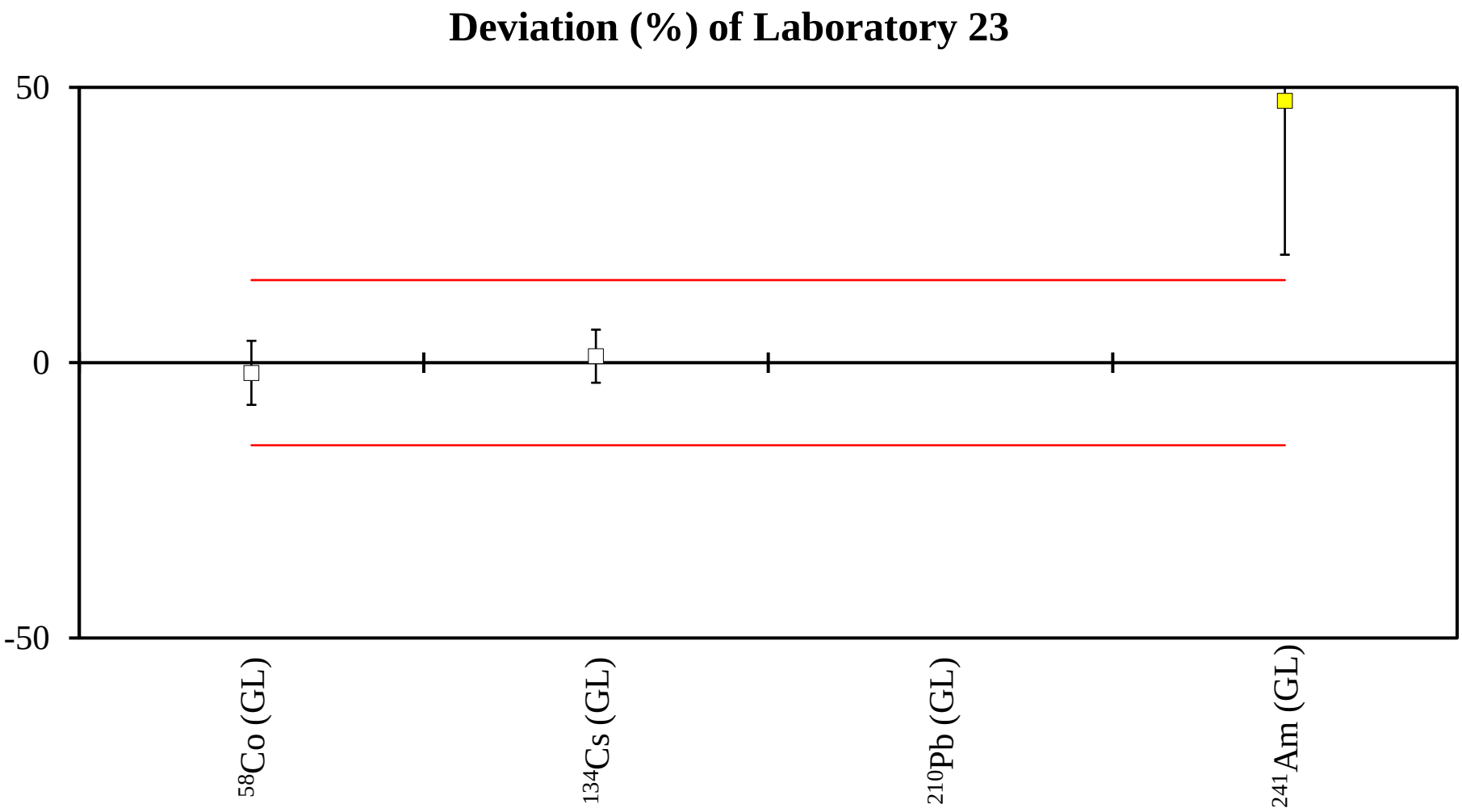

Deviation (%) of Laboratory 15
50
0
-50
58Co (GL)
134Cs (GL)
241Am (GL)

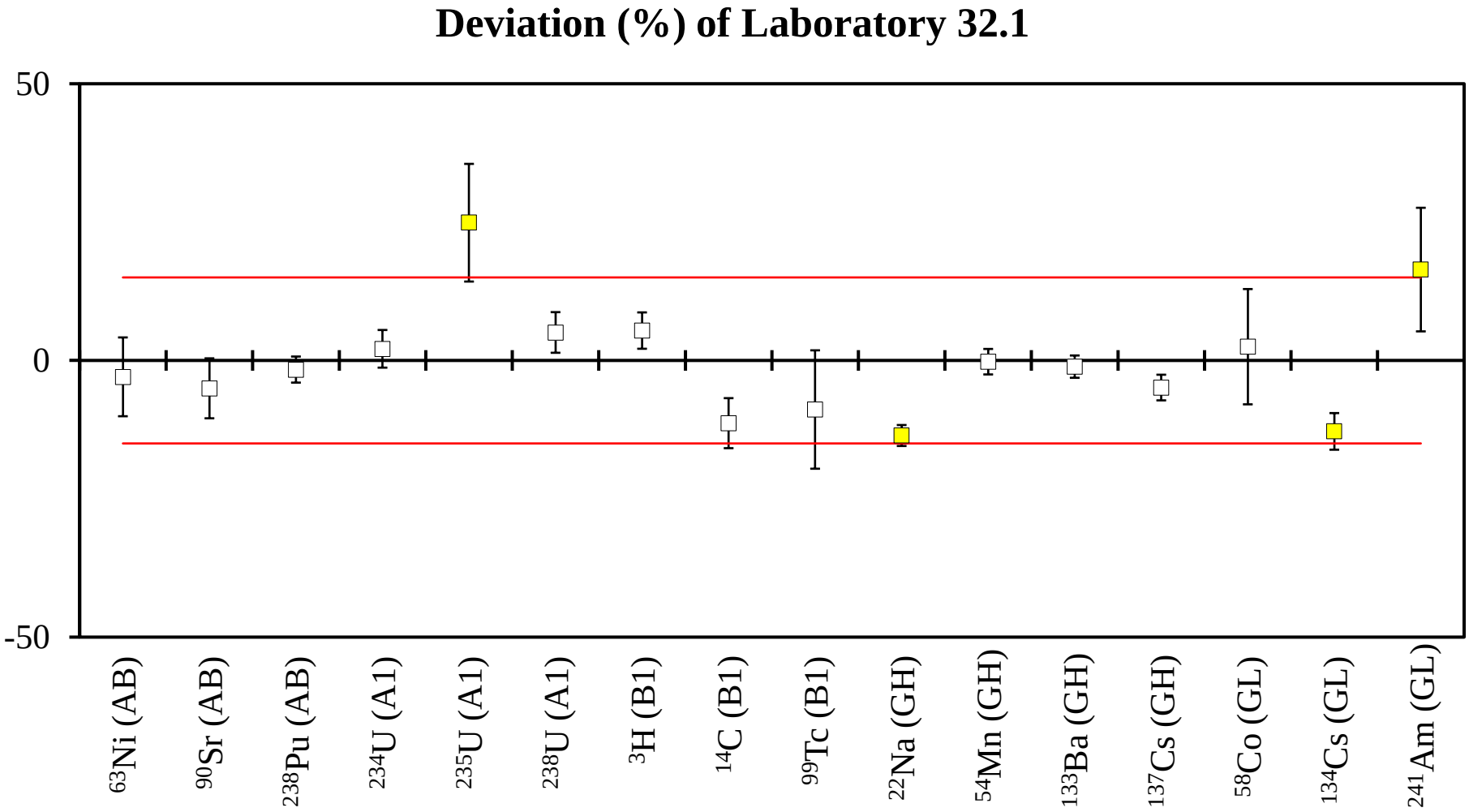
Radionuclide	Laboratory 15	NPL Assigned Value	Deviation (%)	Zeta	Z Score
^{58}Co (GL)	35.3 ± 1.5	34.64 ± 0.24	1.9	0.43	0.33
^{134}Cs (GL)	19.43 ± 0.55	19.57 ± 0.28	-0.7	-0.23	-0.12
^{241}Am (GL)	3.84 ± 0.43	2.5082 ± 0.0054	53.1	3.10	9.12


Deviation (%) of Laboratory 16
50
0
-50
^{3}H (B1)
^{14}C (B1)
^{22}Na (GH)
^{54}Mn (GH)
^{133}Ba (GH)
^{137}Cs (GH)
^{58}Co (GL)
^{134}Cs (GL)

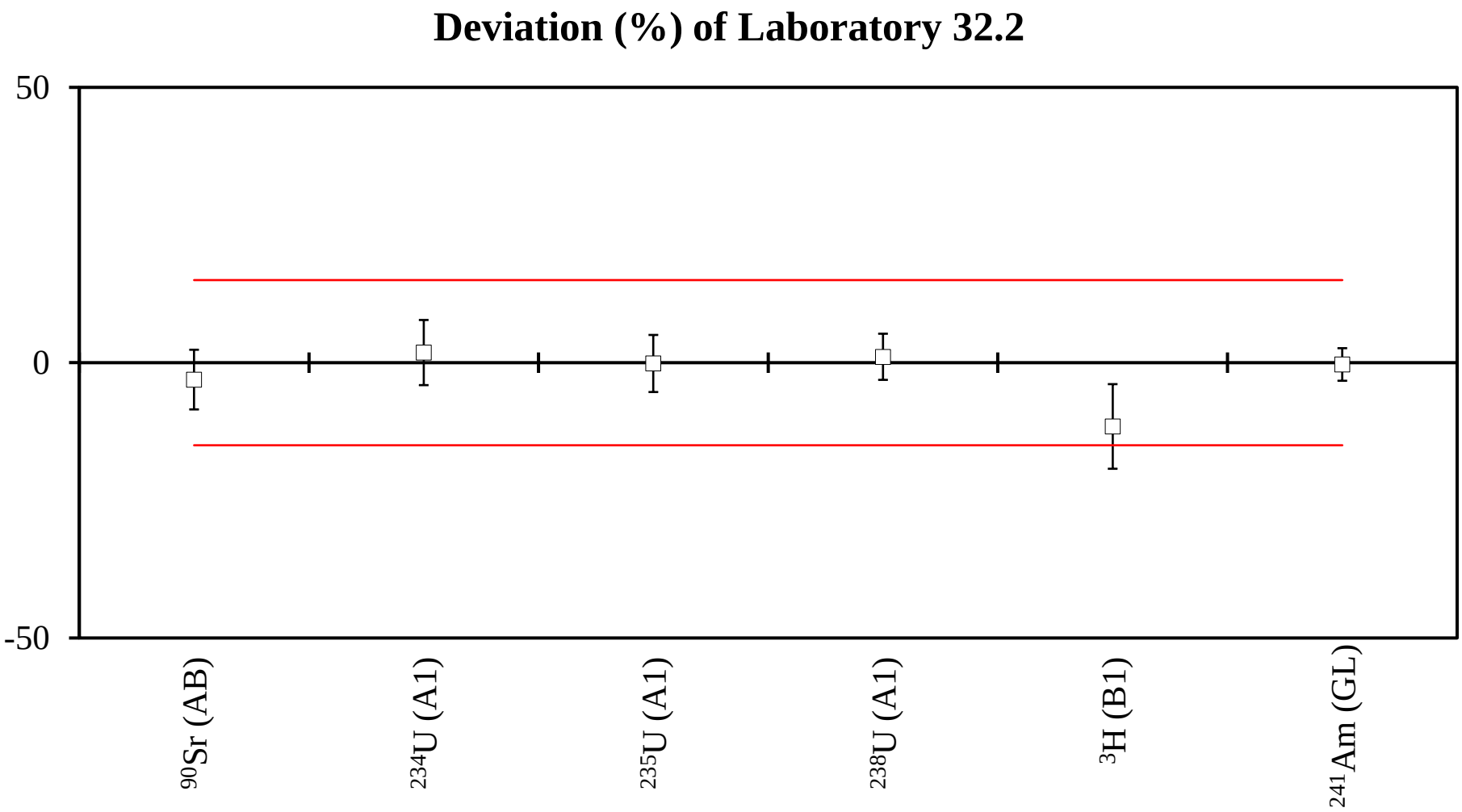
Radionuclide	Laboratory 16	NPL Assigned Value	Deviation (%)	Zeta	Z Score
^{3}H (B1)	0.555 ± 0.022	0.5655 ± 0.0071	-1.9	-0.45	-0.32
^{14}C (B1)	0.170 ± 0.010	0.1720 ± 0.0012	-1.2	-0.20	-0.20
^{22}Na (GH)	16.7 ± 1.2	16.672 ± 0.068	0.2	0.02	0.03
^{54}Mn (GH)	11.60 ± 0.80	11.446 ± 0.043	1.3	0.19	0.23
^{133}Ba (GH)	17.2 ± 1.2	16.94 ± 0.12	1.5	0.22	0.26
^{137}Cs (GH)	8.670 ± 0.6	8.612 ± 0.064	0.7	0.10	0.12
^{58}Co (GL)	27.5 ± 2.1	34.64 ± 0.24	-20.6	-3.38	-3.54
^{134}Cs (GL)	19.6 ± 1.4	19.57 ± 0.28	0.2	0.02	0.03


Deviation (%) of Laboratory 23
50
0
-50
58Co (GL)
134Cs (GL)
210Pb (GL)
241Am (GL)

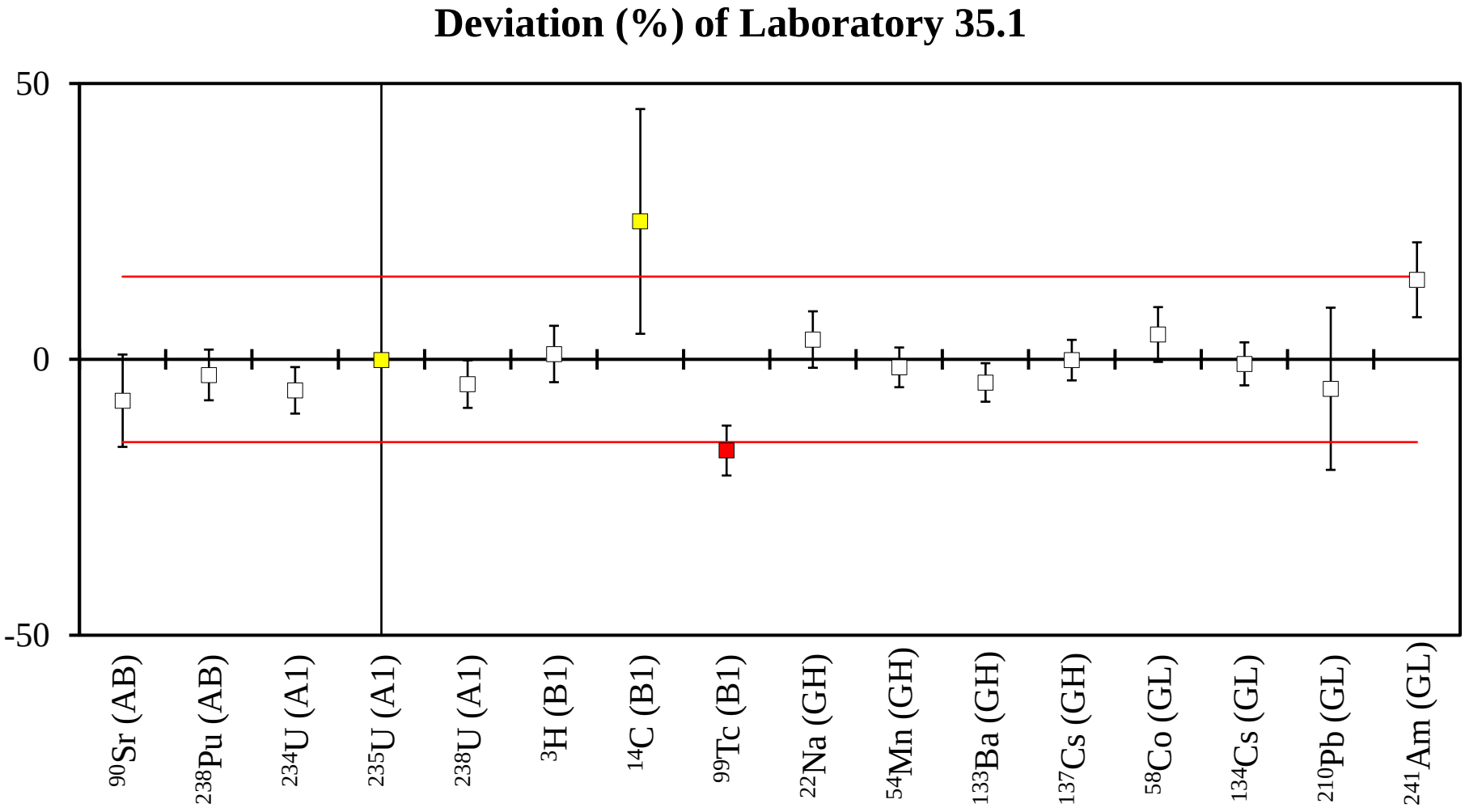
Radionuclide	Laboratory 23	NPL Assigned Value	Deviation (%)	Zeta	Z Score
^{58}Co (GL)	34.0 ± 2.0	34.64 ± 0.24	-1.8	-0.32	-0.32
^{134}Cs (GL)	19.80 ± 0.90	19.57 ± 0.28	1.2	0.24	0.20
^{210}Pb (GL)	37.0 ± 4.0	15.00 ± 0.16	146.7	5.50	25.19
^{241}Am (GL)	3.7 ± 0.7	2.5082 ± 0.0054	47.5	1.70	8.16


Deviation (%) of Laboratory 32.1
50
0
-50
63Ni (AB)
90Sr (AB)
238Pu (AB)
234U (A1)
235U (A1)
238U (A1)
3H (B1)
14C (B1)
99Tc (B1)
22Na (GH)
54Mn (GH)
133Ba (GH)
137Cs (GH)
58Co (GL)
134Cs (GL)
241Am (GL)

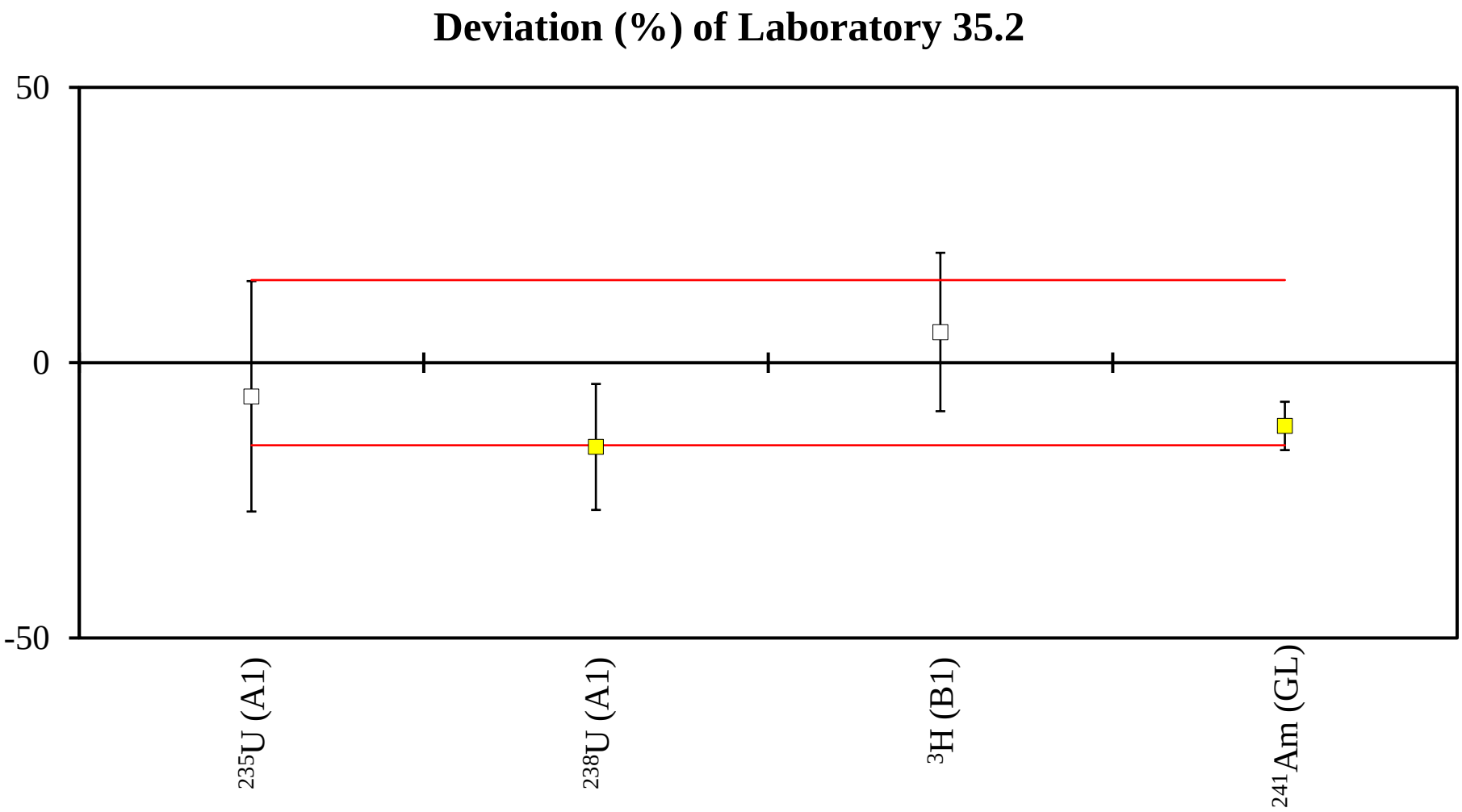
Radionuclide	Laboratory 32.1	NPL Assigned Value	Deviation (%)	Zeta	Z Score
^{63}Ni (AB)	1.93 ± 0.14	1.989 ± 0.022	-3.0	-0.42	-0.51
^{90}Sr (AB)	1.93 ± 0.11	2.0324 ± 0.0054	-5.0	-0.93	-0.87
^{238}Pu (AB)	9.22 ± 0.22	9.375 ± 0.021	-1.7	-0.70	-0.28
^{234}U (A1)	19.45 ± 0.60	19.05 ± 0.24	2.1	0.62	0.36
^{235}U (A1)	0.838 ± 0.070	0.671 ± 0.011	24.9	2.36	4.27
^{238}U (A1)	14.76 ± 0.48	14.05 ± 0.18	5.1	1.38	0.87
^{3}H (B1)	0.596 ± 0.017	0.5655 ± 0.0071	5.4	1.66	0.93
^{14}C (B1)	0.1525 ± 0.0077	0.1720 ± 0.0012	-11.3	-2.50	-1.95
^{99}Tc (B1)	0.188 ± 0.022	0.2063 ± 0.0019	-8.9	-0.83	-1.52
^{22}Na (GH)	14.41 ± 0.31	16.672 ± 0.068	-13.6	-7.13	-2.33
^{54}Mn (GH)	11.42 ± 0.26	11.446 ± 0.043	-0.2	-0.10	-0.04
^{133}Ba (GH)	16.75 ± 0.32	16.94 ± 0.12	-1.1	-0.56	-0.19
^{137}Cs (GH)	8.19 ± 0.19	8.612 ± 0.064	-4.9	-2.10	-0.84
^{58}Co (GL)	35.5 ± 3.6	34.64 ± 0.24	2.5	0.24	0.43
^{134}Cs (GL)	17.06 ± 0.60	19.57 ± 0.28	-12.8	-3.79	-2.20
^{241}Am (GL)	2.92 ± 0.28	2.5082 ± 0.0054	16.4	1.47	2.82


Deviation (%) of Laboratory 32.2
50
0
-50
90Sr (AB)
234U (A1)
235U (A1)
238U (A1)
3H (B1)
241Am (GL)

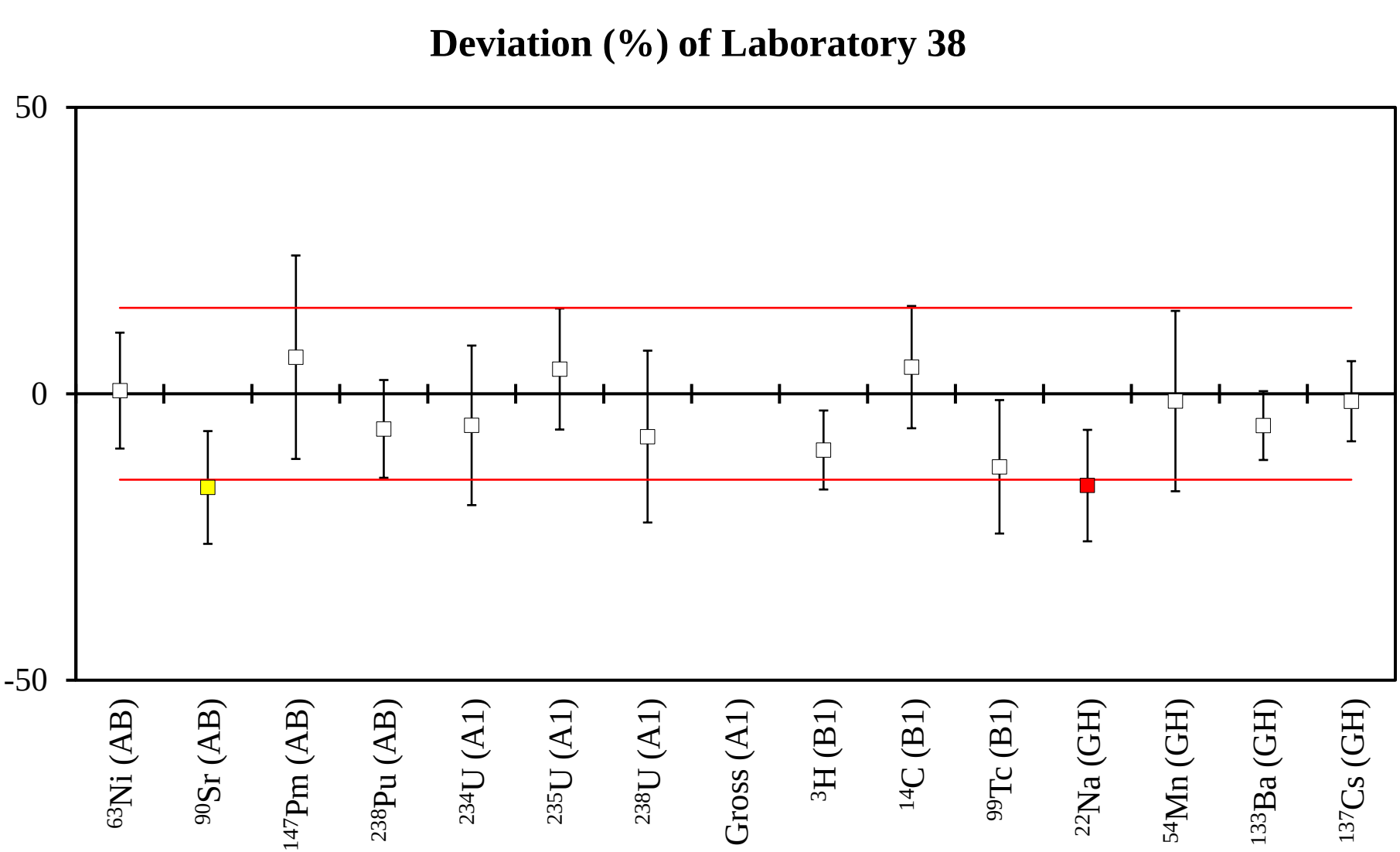
Radionuclide	Laboratory 32.2	NPL Assigned Value	Deviation (%)	Zeta	Z Score
^{90}Sr (AB)	1.97 ± 0.11	2.0324 ± 0.0054	-3.1	-0.57	-0.53
^{234}U (A1)	19.4 ± 1.1	19.05 ± 0.24	1.8	0.31	0.32
^{235}U (A1)	0.670 ± 0.033	0.671 ± 0.011	-0.1	-0.03	-0.03
^{238}U (A1)	14.20 ± 0.56	14.05 ± 0.18	1.1	0.26	0.18
^{3}H (B1)	0.500 ± 0.043	0.5655 ± 0.0071	-11.6	-1.50	-1.99
^{241}Am (GL)	2.500 ± 0.074	2.5082 ± 0.0054	-0.3	-0.11	-0.06


Deviation (%) of Laboratory 35.1
50
0
-50
90Sr (AB)
238Pu (AB)
234U (A1)
235U (A1)
238U (A1)
3H (B1)
14C (B1)
99Tc (B1)
22Na (GH)
54Mn (GH)
133Ba (GH)
137Cs (GH)
58Co (GL)
134Cs (GL)
210Pb (GL)
241Am (GL)

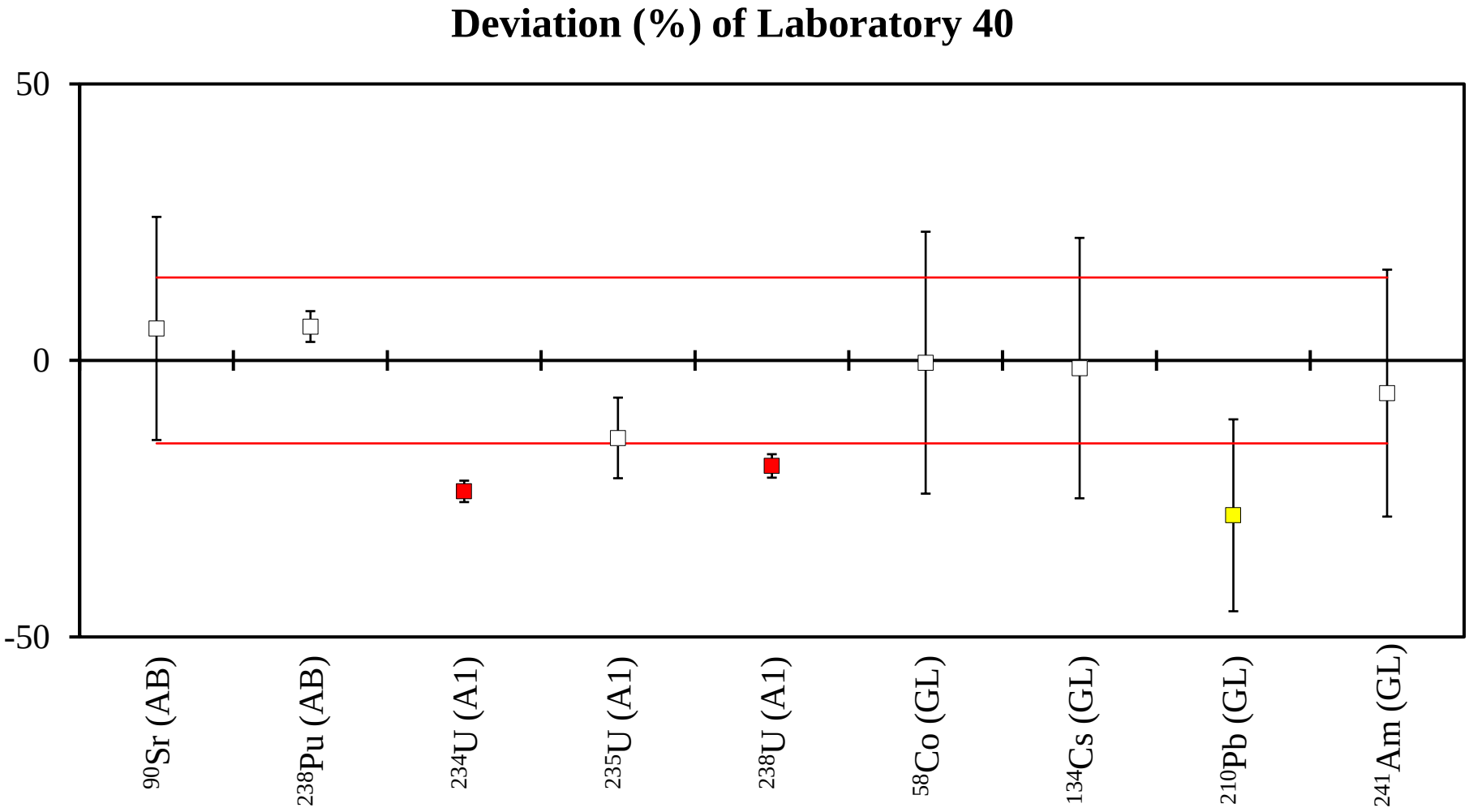
Radionuclide	Laboratory 35.1	NPL Assigned Value	Deviation (%)	Zeta	Z Score
^{90}Sr (AB)	1.88 ± 0.17	2.0324 ± 0.0054	-7.5	-0.90	-1.29
^{238}Pu (AB)	9.11 ± 0.43	9.375 ± 0.021	-2.8	-0.62	-0.49
^{234}U (A1)	17.98 ± 0.77	19.05 ± 0.24	-5.6	-1.33	-0.96
^{235}U (A1)	0.67 ± 0.34	0.671 ± 0.011	-0.1	0.00	-0.03
^{238}U (A1)	13.42 ± 0.58	14.05 ± 0.18	-4.5	-1.04	-0.77
^{3}H (B1)	0.571 ± 0.028	0.5655 ± 0.0071	1.0	0.19	0.17
^{14}C (B1)	0.215 ± 0.035	0.1720 ± 0.0012	25.0	1.23	4.29
^{99}Tc (B1)	0.1722 ± 0.0092	0.2063 ± 0.0019	-16.5	-3.63	-2.84
^{22}Na (GH)	17.27 ± 0.85	16.672 ± 0.068	3.6	0.70	0.62
^{54}Mn (GH)	11.28 ± 0.41	11.446 ± 0.043	-1.5	-0.40	-0.25
^{133}Ba (GH)	16.23 ± 0.58	16.94 ± 0.12	-4.2	-1.20	-0.72
^{137}Cs (GH)	8.60 ± 0.31	8.612 ± 0.064	-0.1	-0.04	-0.02
^{58}Co (GL)	36.2 ± 1.7	34.64 ± 0.24	4.5	0.91	0.77
^{134}Cs (GL)	19.41 ± 0.71	19.57 ± 0.28	-0.8	-0.21	-0.14
^{210}Pb (GL)	14.2 ± 2.2	15.00 ± 0.16	-5.3	-0.36	-0.92
^{241}Am (GL)	2.87 ± 0.17	2.5082 ± 0.0054	14.4	2.13	2.48


Deviation (%) of Laboratory 35.2
50
0
-50
235U (A1)
238U (A1)
3H (B1)
241Am (GL)

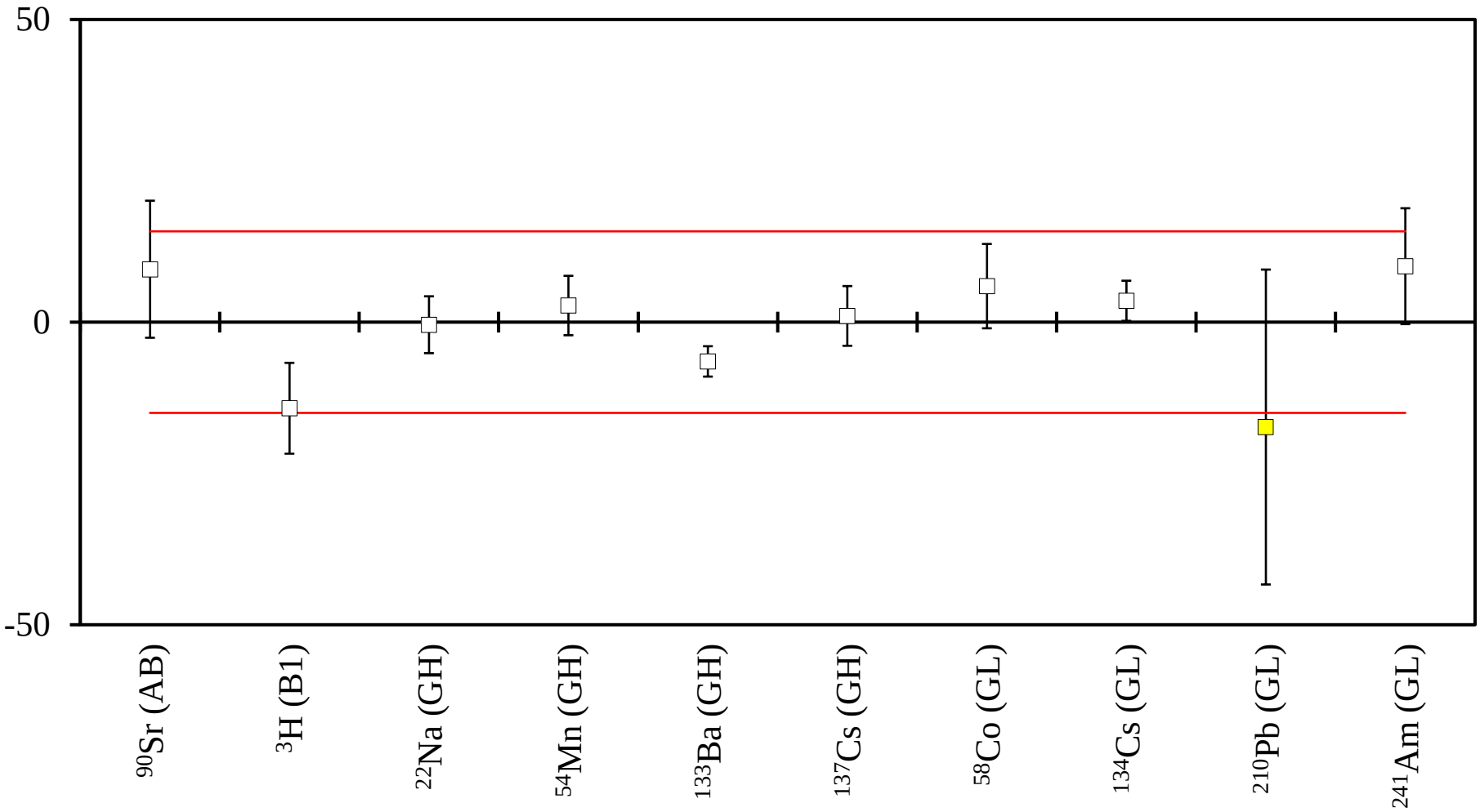
Radionuclide	Laboratory 35.2	NPL Assigned Value	Deviation (%)	Zeta	Z Score
^{235}U (A1)	0.63 ± 0.14	0.671 ± 0.011	-6.1	-0.29	-1.05
^{238}U (A1)	11.9 ± 1.6	14.05 ± 0.18	-15.3	-1.34	-2.63
^{3}H (B1)	0.597 ± 0.081	0.5655 ± 0.0071	5.6	0.39	0.96
^{241}Am (GL)	2.22 ± 0.11	2.5082 ± 0.0054	-11.5	-2.62	-1.97


Deviation (%) of Laboratory 38
50
0
-50
63Ni (AB)
90Sr (AB)
147Pm (AB)
238Pu (AB)
234U (A1)
235U (A1)
238U (A1)
Gross (A1)
3H (B1)
14C (B1)
99Tc (B1)
22Na (GH)
54Mn (GH)
133Ba (GH)
137Cs (GH)

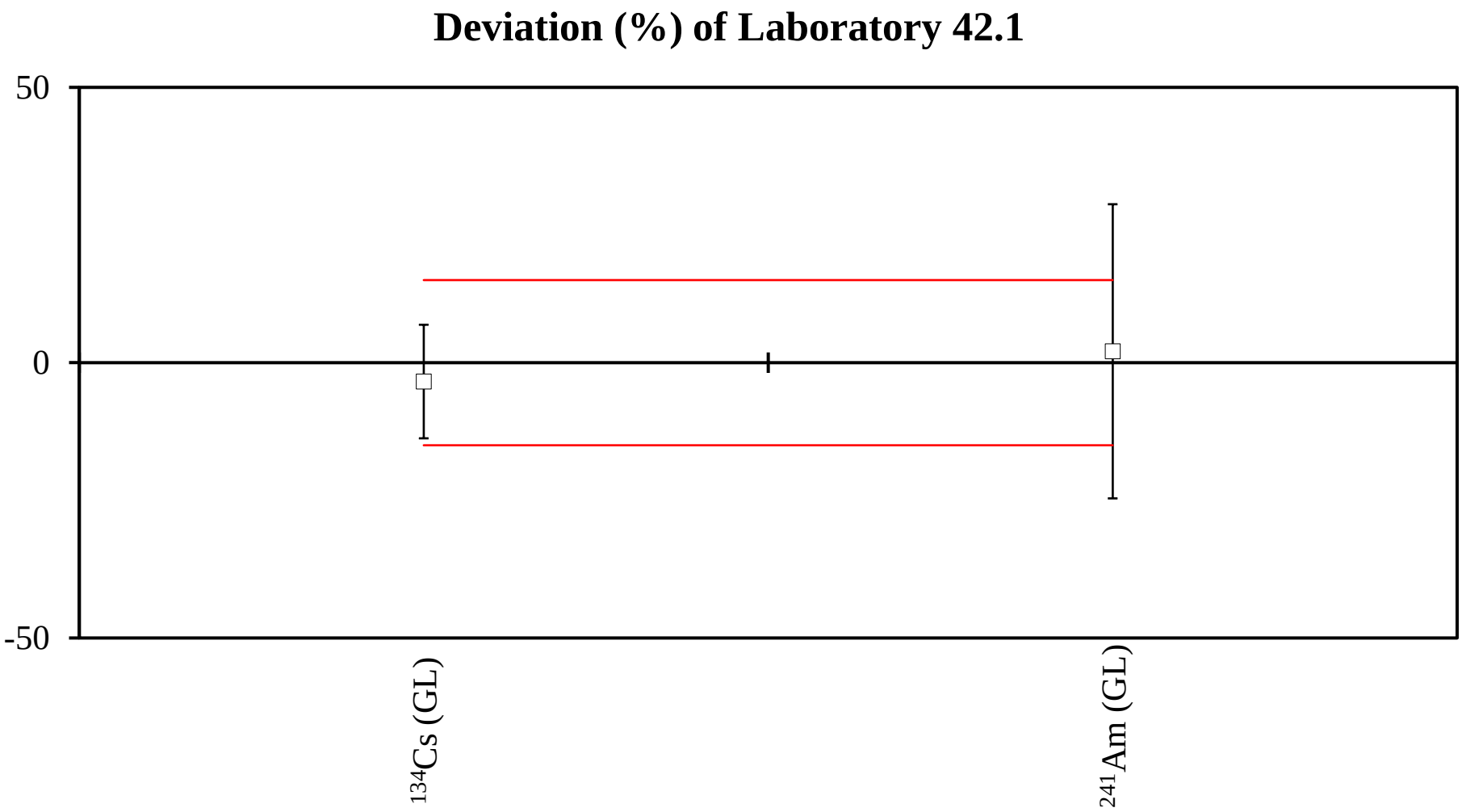
Radionuclide	Laboratory 38	NPL Assigned Value	Deviation (%)	Zeta	Z Score
^{63}Ni (AB)	2.00 ± 0.20	1.989 ± 0.022	0.6	0.05	0.09
^{90}Sr (AB)	1.70 ± 0.20	2.0324 ± 0.0054	-16.4	-1.66	-2.81
^{147}Pm (AB)	18.0 ± 3.0	16.92 ± 0.16	6.4	0.36	1.10
^{238}Pu (AB)	8.80 ± 0.80	9.375 ± 0.021	-6.1	-0.72	-1.05
Gross beta (AB)	7.6 ± 0.6	-	-	-	-
^{234}U (A1)	18.0 ± 2.0	19.05 ± 0.24	-5.5	-0.52	-0.95
^{235}U (A1)	0.70 ± 0.10	0.671 ± 0.011	4.3	0.29	0.74
^{238}U (A1)	13.00 ± 0.90	14.05 ± 0.18	-7.5	-1.14	-1.28
Gross alpha (A1)	11.0 ± 2.0	30.5 ± 1.8	-63.9	-7.25	-10.98
^{3}H (B1)	0.51 ± 0.06	0.5655 ± 0.0071	-9.8	-0.92	-1.69
^{14}C (B1)	0.180 ± 0.020	0.1720 ± 0.0012	4.7	0.40	0.80
^{99}Tc (B1)	0.180 ± 0.020	0.2063 ± 0.0019	-12.7	-1.31	-2.19
Gross beta (B1)	0.277 ± 0.009	-	-	-	-
^{22}Na (GH)	14.0 ± 1.0	16.672 ± 0.068	-16.0	-2.67	-2.75
^{54}Mn (GH)	11.30 ± 0.80	11.446 ± 0.043	-1.3	-0.18	-0.22
^{133}Ba (GH)	16.0 ± 1.0	16.94 ± 0.12	-5.5	-0.93	-0.95
^{137}Cs (GH)	8.5 ± 0.6	8.612 ± 0.064	-1.3	-0.19	-0.22


Deviation (%) of Laboratory 40
50
0
-50
90Sr (AB)
238Pu (AB)
234U (A1)
235U (A1)
238U (A1)
58Co (GL)
134Cs (GL)
210Pb (GL)
241Am (GL)

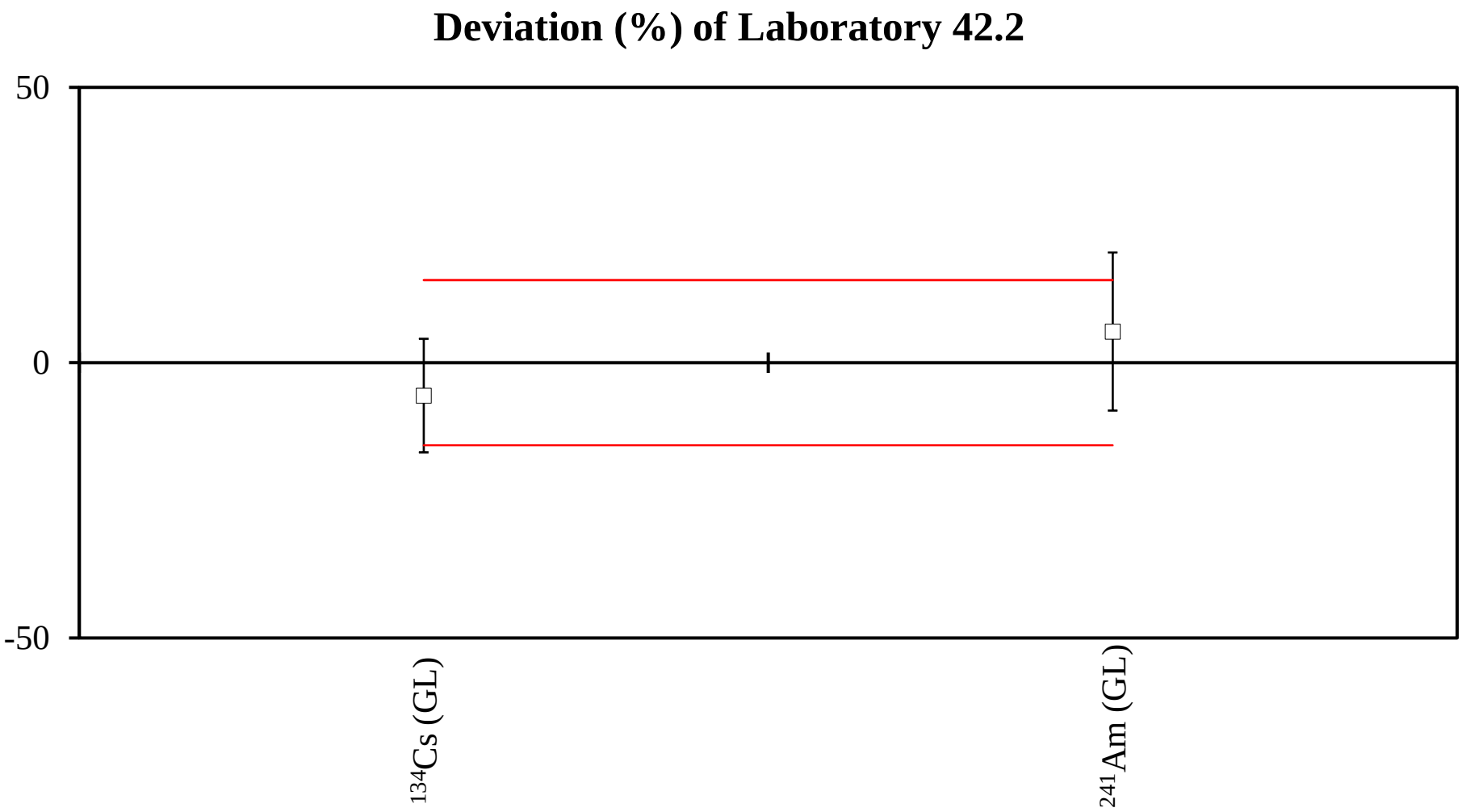
Radionuclide	Laboratory 40	NPL Assigned Value	Deviation (%)	Zeta	Z Score
^{90}Sr (AB)	2.15 ± 0.41	2.0324 ± 0.0054	5.8	0.29	0.99
^{238}Pu (AB)	9.95 ± 0.26	9.375 ± 0.021	6.1	2.20	1.05
^{234}U (A1)	14.54 ± 0.32	19.05 ± 0.24	-23.7	-11.28	-4.07
^{235}U (A1)	0.577 ± 0.048	0.671 ± 0.011	-14.0	-1.91	-2.41
^{238}U (A1)	11.37 ± 0.26	14.05 ± 0.18	-19.1	-8.47	-3.28
^{58}Co (GL)	34.5 ± 8.2	34.64 ± 0.24	-0.4	-0.02	-0.07
^{134}Cs (GL)	19.3 ± 4.6	19.57 ± 0.28	-1.4	-0.06	-0.24
^{210}Pb (GL)	10.8 ± 2.6	15.00 ± 0.16	-28.0	-1.61	-4.81
^{241}Am (GL)	2.36 ± 0.56	2.5082 ± 0.0054	-5.9	-0.26	-1.01


Deviation (%) of Laboratory 41
50
0
-50
90Sr (AB)
3H (B1)
22Na (GH)
54Mn (GH)
133Ba (GH)
137Cs (GH)
58Co (GL)
134Cs (GL)
210Pb (GL)
241Am (GL)

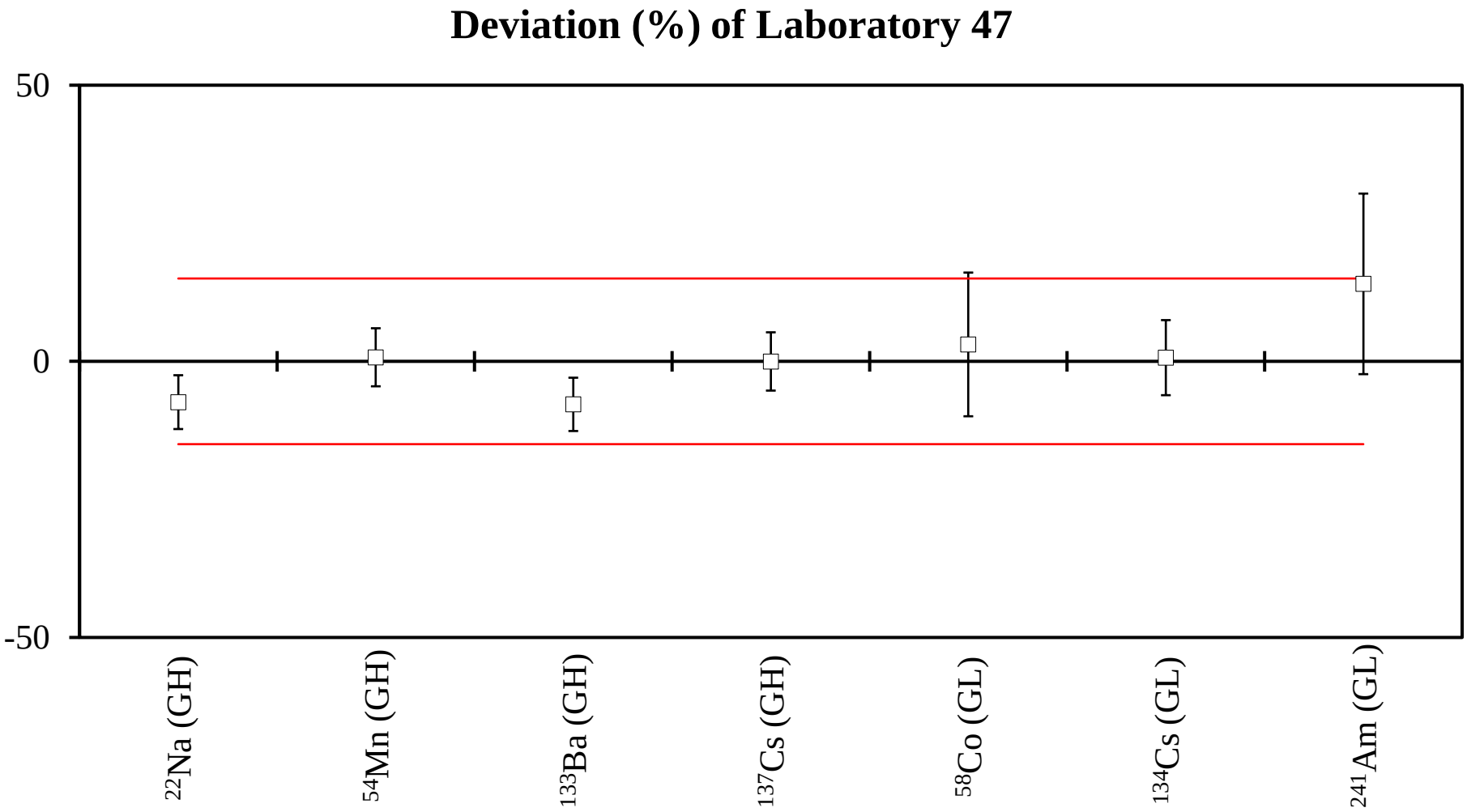
Radionuclide	Laboratory 41	NPL Assigned Value	Deviation (%)	Zeta	Z Score
^{90}Sr (AB)	2.21 ± 0.23	2.0324 ± 0.0054	8.7	0.77	1.50
^{3}H (B1)	0.485 ± 0.042	0.5655 ± 0.0071	-14.2	-1.89	-2.44
^{22}Na (GH)	16.60 ± 0.78	16.672 ± 0.068	-0.4	-0.09	-0.07
^{54}Mn (GH)	11.76 ± 0.56	11.446 ± 0.043	2.7	0.56	0.47
^{133}Ba (GH)	15.84 ± 0.41	16.94 ± 0.12	-6.5	-2.57	-1.12
^{137}Cs (GH)	8.70 ± 0.42	8.612 ± 0.064	1.0	0.21	0.18
^{58}Co (GL)	36.7 ± 2.4	34.64 ± 0.24	5.9	0.85	1.02
^{134}Cs (GL)	20.26 ± 0.58	19.57 ± 0.28	3.5	1.07	0.61
^{210}Pb (GL)	12.4 ± 3.9	15.00 ± 0.16	-17.3	-0.67	-2.98
^{241}Am (GL)	2.74 ± 0.24	2.5082 ± 0.0054	9.2	0.97	1.59


Deviation (%) of Laboratory 42.1
50
0
-50
134Cs (GL)
241Am (GL)

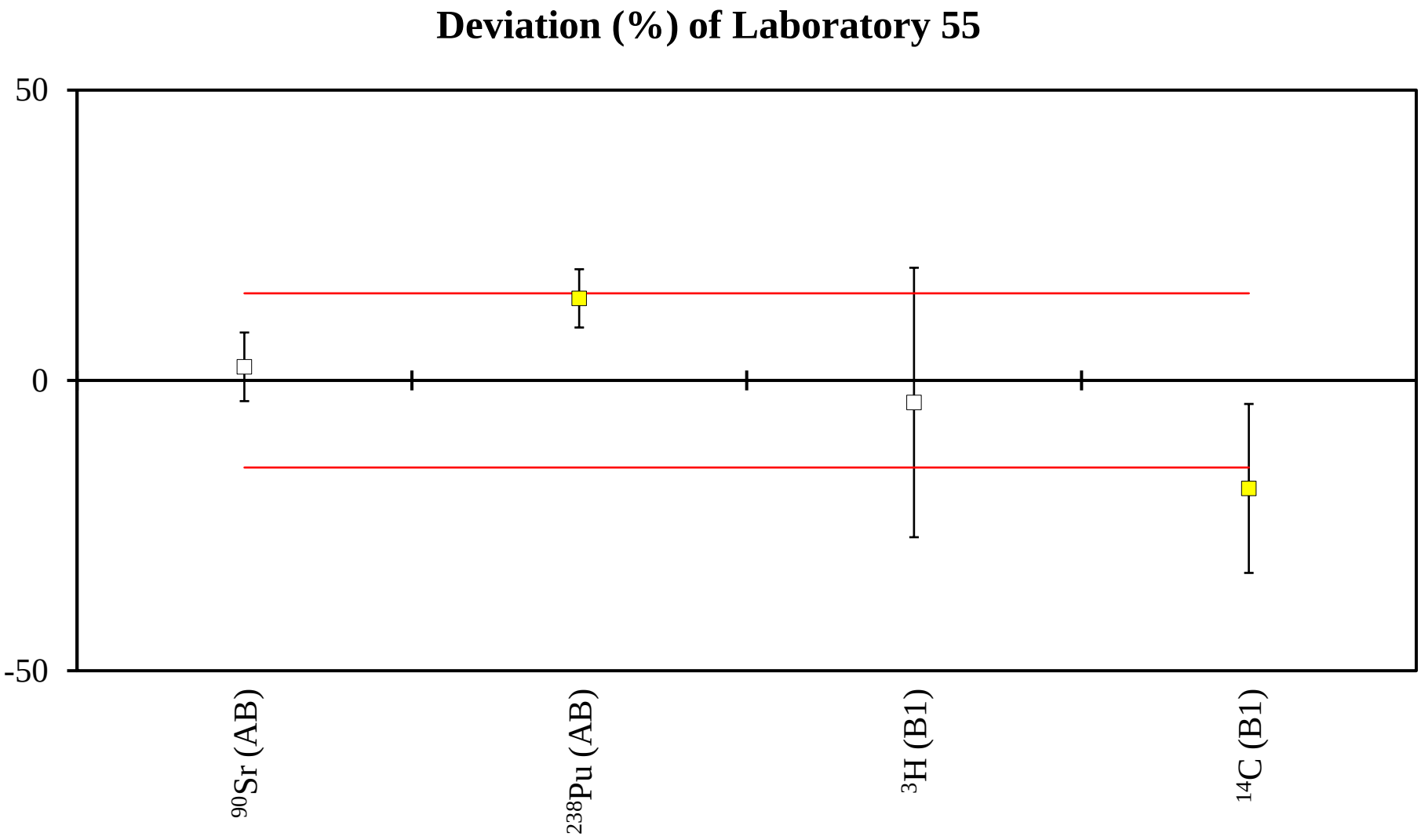
Radionuclide	Laboratory 42.1	NPL Assigned Value	Deviation (%)	Zeta	Z Score
^{134}Cs (GL)	18.9 ± 2.0	19.57 ± 0.28	-3.4	-0.33	-0.59
^{241}Am (GL)	2.56 ± 0.67	2.5082 ± 0.0054	2.1	0.08	0.35


Deviation (%) of Laboratory 42.2
50
0
-50
134Cs (GL)
241Am (GL)

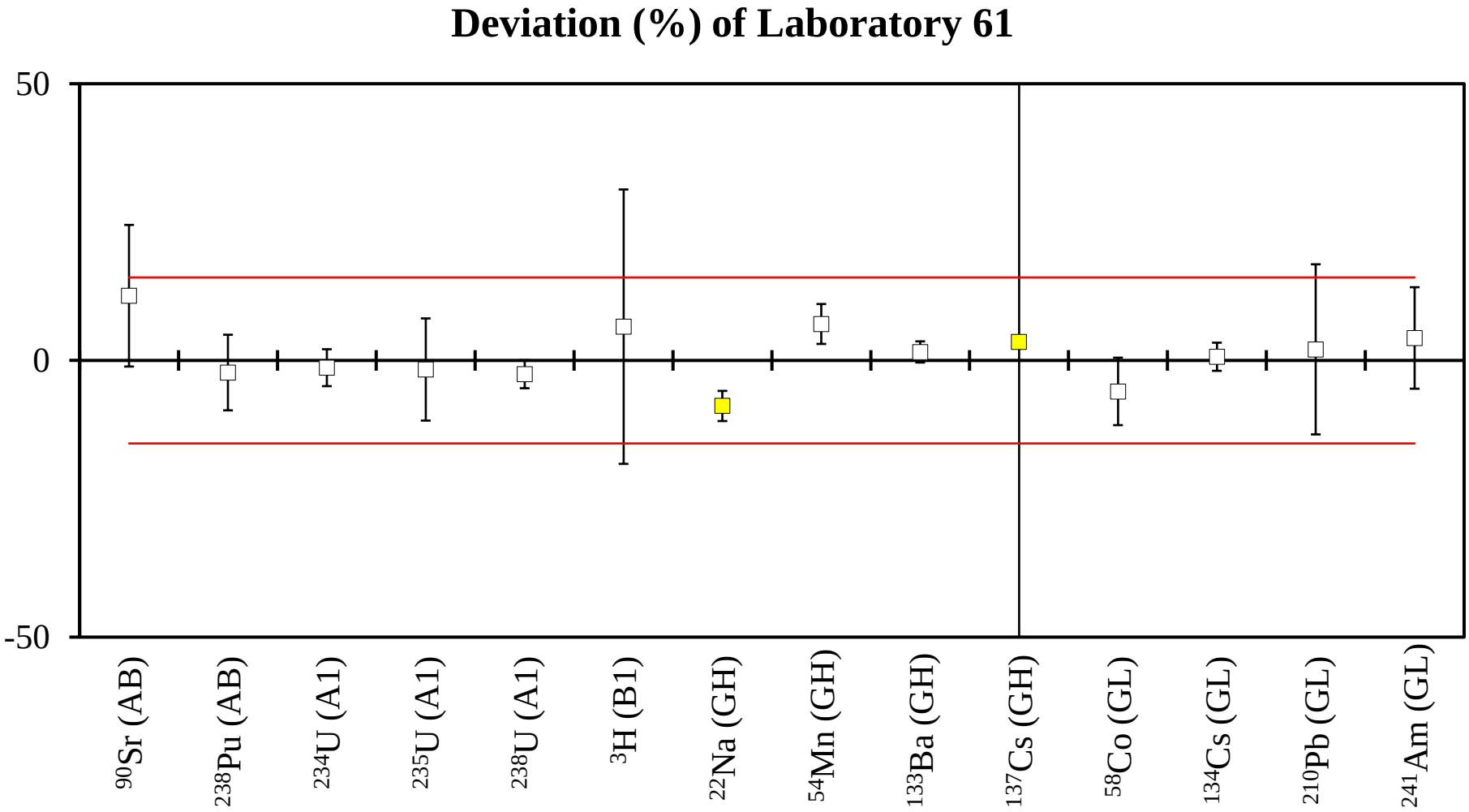
Radionuclide	Laboratory 42.2	NPL Assigned Value	Deviation (%)	Zeta	Z Score
^{134}Cs (GL)	18.4 ± 2.0	19.57 ± 0.28	-6.0	-0.58	-1.03
^{241}Am (GL)	2.65 ± 0.36	2.5082 ± 0.0054	5.7	0.39	0.97


Deviation (%) of Laboratory 47
50
0
-50
22Na (GH)
54Mn (GH)
133Ba (GH)
137Cs (GH)
58Co (GL)
134Cs (GL)
241Am (GL)

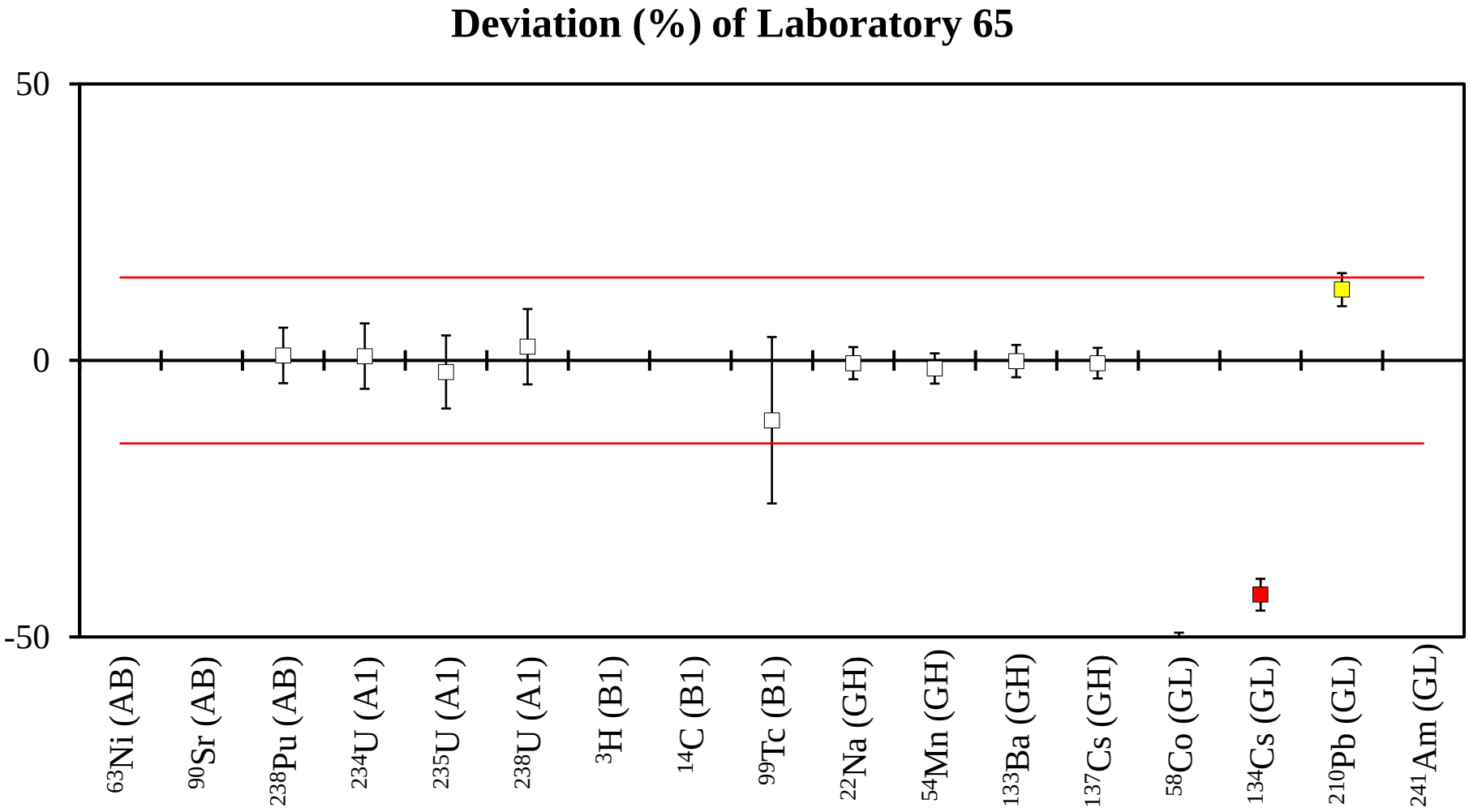
Radionuclide	Laboratory 47	NPL Assigned Value	Deviation (%)	Zeta	Z Score
^{22}Na (GH)	15.44 ± 0.81	16.672 ± 0.068	-7.4	-1.52	-1.27
^{54}Mn (GH)	11.53 ± 0.60	11.446 ± 0.043	0.7	0.14	0.13
^{133}Ba (GH)	15.62 ± 0.81	16.94 ± 0.12	-7.8	-1.61	-1.34
^{137}Cs (GH)	8.61 ± 0.45	8.612 ± 0.064	0.0	0.00	0.00
^{58}Co (GL)	35.7 ± 4.5	34.64 ± 0.24	3.1	0.24	0.53
^{134}Cs (GL)	19.7 ± 1.3	19.57 ± 0.28	0.7	0.10	0.11
^{241}Am (GL)	2.86 ± 0.41	2.5082 ± 0.0054	14.0	0.86	2.41


Deviation (%) of Laboratory 55
50
0
-50
^{90}Sr (AB)
^{238}Pu (AB)
^{3}H (B1)
^{14}C (B1)

Radionuclide	Laboratory 55	NPL Assigned Value	Deviation (%)	Zeta	Z Score
^{90}Sr (AB)	2.08 ± 0.12	2.0324 ± 0.0054	2.3	0.40	0.40
^{238}Pu (AB)	10.70 ± 0.47	9.375 ± 0.021	14.1	2.82	2.43
Gross beta (AB)	11.1 ± 1.5	-	-	-	-
^{3}H (B1)	0.544 ± 0.082	0.5655 ± 0.0071	-3.8	-0.26	-0.65
^{14}C (B1)	0.140 ± 0.016	0.1720 ± 0.0012	-18.6	-1.99	-3.20

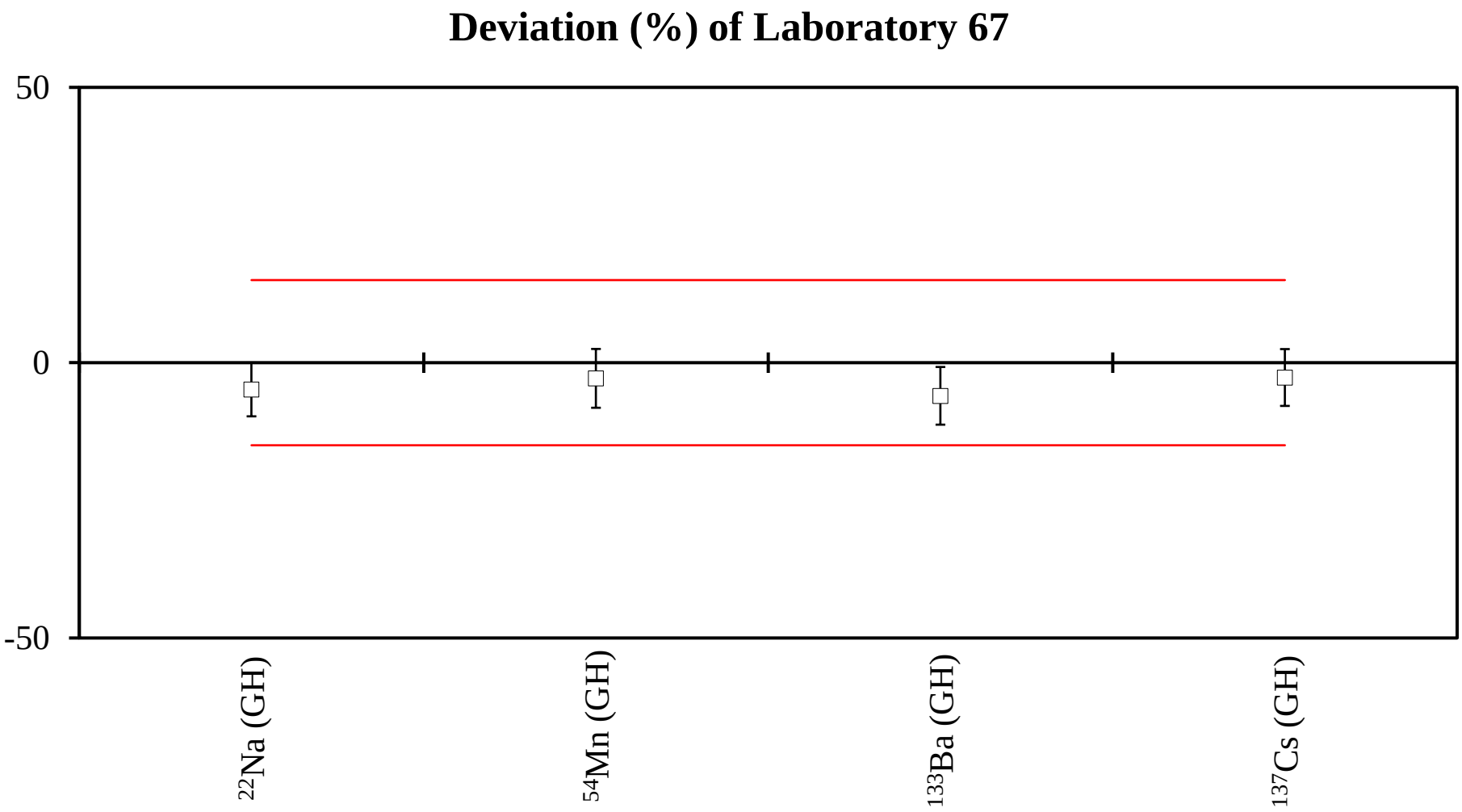

Deviation (%) of Laboratory 61
50
0
-50
90Sr (AB)
238Pu (AB)
234U (A1)
235U (A1)
238U (A1)
3H (B1)
22Na (GH)
54Mn (GH)
133Ba (GH)
137Cs (GH)
58Co (GL)
134Cs (GL)
210Pb (GL)
241Am (GL)

Radionuclide	Laboratory 61	NPL Assigned Value	Deviation (%)	Zeta	Z Score
^{90}Sr (AB)	2.27 ± 0.26	2.0324 ± 0.0054	11.7	0.91	2.01
^{238}Pu (AB)	9.17 ± 0.64	9.375 ± 0.021	-2.2	-0.32	-0.38
^{234}U (A1)	18.80 ± 0.59	19.05 ± 0.24	-1.3	-0.39	-0.23
^{235}U (A1)	0.660 ± 0.061	0.671 ± 0.011	-1.6	-0.18	-0.28
^{238}U (A1)	13.70 ± 0.31	14.05 ± 0.18	-2.5	-0.98	-0.43
^{3}H (B1)	0.60 ± 0.14	0.5655 ± 0.0071	6.1	0.25	1.05
^{22}Na (GH)	15.30 ± 0.45	16.672 ± 0.068	-8.2	-3.01	-1.41
^{54}Mn (GH)	12.20 ± 0.41	11.446 ± 0.043	6.6	1.83	1.13
^{133}Ba (GH)	17.2 ± 0.3	16.94 ± 0.12	1.5	0.80	0.26
^{137}Cs (GH)	8.9 ± 5.0	8.612 ± 0.064	3.3	0.06	0.57
^{58}Co (GL)	32.7 ± 2.1	34.64 ± 0.24	-5.6	-0.92	-0.96
^{134}Cs (GL)	19.70 ± 0.41	19.57 ± 0.28	0.7	0.26	0.11
^{210}Pb (GL)	15.3 ± 2.3	15.00 ± 0.16	2.0	0.13	0.34
^{241}Am (GL)	2.61 ± 0.23	2.5082 ± 0.0054	4.1	0.44	0.70

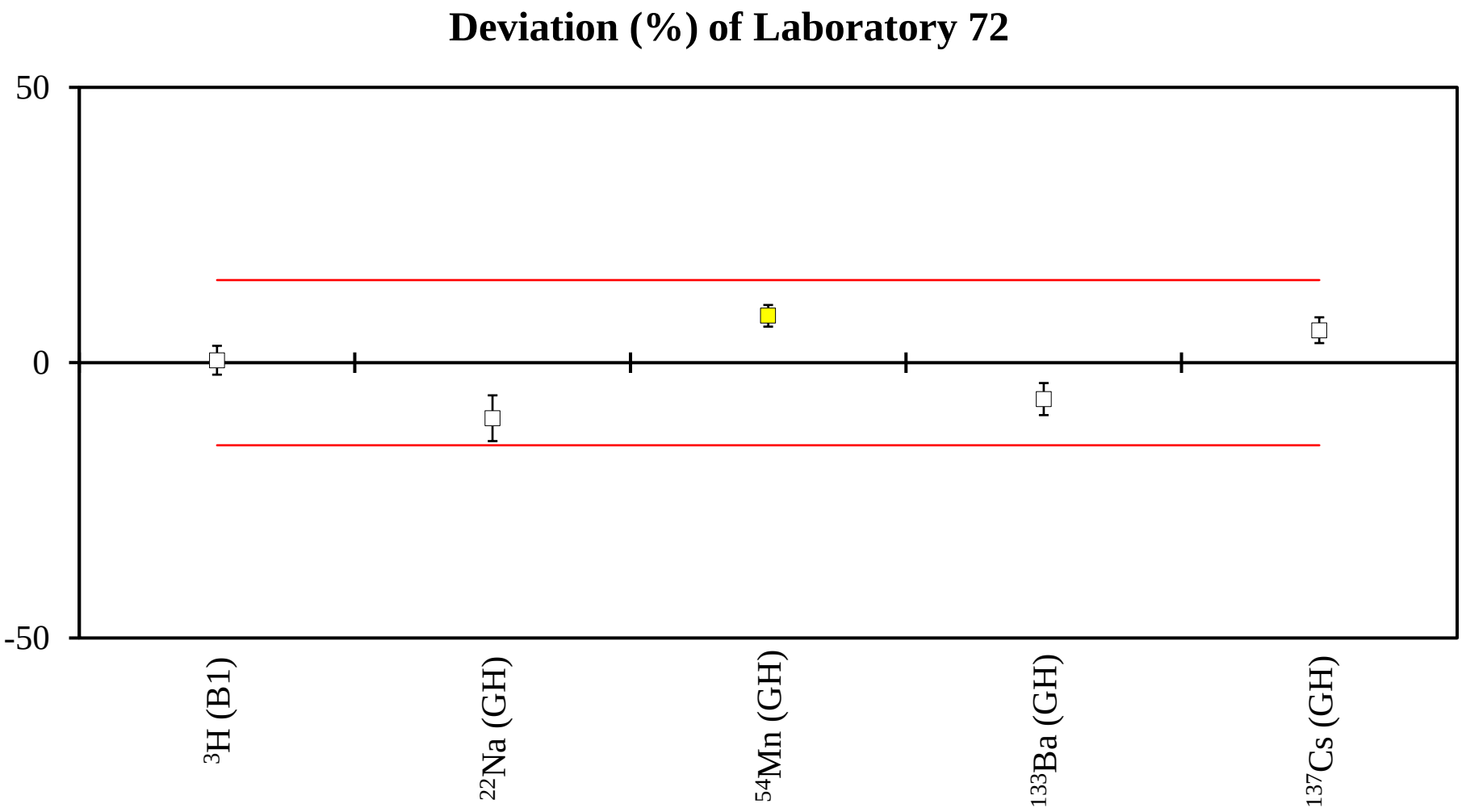

Deviation (%) of Laboratory 65
50
0
-50
63Ni (AB)
90Sr (AB)
238Pu (AB)
234U (A1)
235U (A1)
238U (A1)
3H (B1)
14C (B1)
99Tc (B1)
22Na (GH)
54Mn (GH)
133Ba (GH)
137Cs (GH)
58Co (GL)
134Cs (GL)
210Pb (GL)
241Am (GL)

Radionuclide	Laboratory 65	NPL Assigned Value	Deviation (%)	Zeta	Z Score
^{63}Ni (AB)	17.3 ± 1.3	1.989 ± 0.022	769.8	11.78	132.20
^{90}Sr (AB)	3.31 ± 0.24	2.0324 ± 0.0054	62.9	5.32	10.80
^{238}Pu (AB)	9.46 ± 0.47	9.375 ± 0.021	0.9	0.18	0.16
^{234}U (A1)	19.2 ± 1.1	19.05 ± 0.24	0.8	0.13	0.14
^{235}U (A1)	0.657 ± 0.043	0.671 ± 0.011	-2.1	-0.32	-0.36
^{238}U (A1)	14.40 ± 0.94	14.05 ± 0.18	2.5	0.37	0.43
^{3}H (B1)	52.1 ± 5.3	0.5655 ± 0.0071	9113.1	9.72	1565.02
^{14}C (B1)	26.7 ± 2.2	0.1720 ± 0.0012	15423.3	12.06	2648.68
^{99}Tc (B1)	0.184 ± 0.031	0.2063 ± 0.0019	-10.8	-0.72	-1.86
^{22}Na (GH)	16.59 ± 0.48	16.672 ± 0.068	-0.5	-0.17	-0.08
^{54}Mn (GH)	11.28 ± 0.31	11.446 ± 0.043	-1.5	-0.53	-0.25
^{133}Ba (GH)	16.92 ± 0.48	16.94 ± 0.12	-0.1	-0.04	-0.02
^{137}Cs (GH)	8.57 ± 0.23	8.612 ± 0.064	-0.5	-0.18	-0.08
^{58}Co (GL)[2]	16.59 ± 0.99	34.64 ± 0.24	-52.1	-17.72	-8.95
^{134}Cs (GL)	11.28 ± 0.54	19.57 ± 0.28	-42.4	-13.63	-7.27
^{210}Pb (GL)	16.92 ± 0.41	15.00 ± 0.16	12.8	4.36	2.20
^{241}Am (GL)	8.569 ± 0.073	2.5082 ± 0.0054	241.6	82.80	41.50

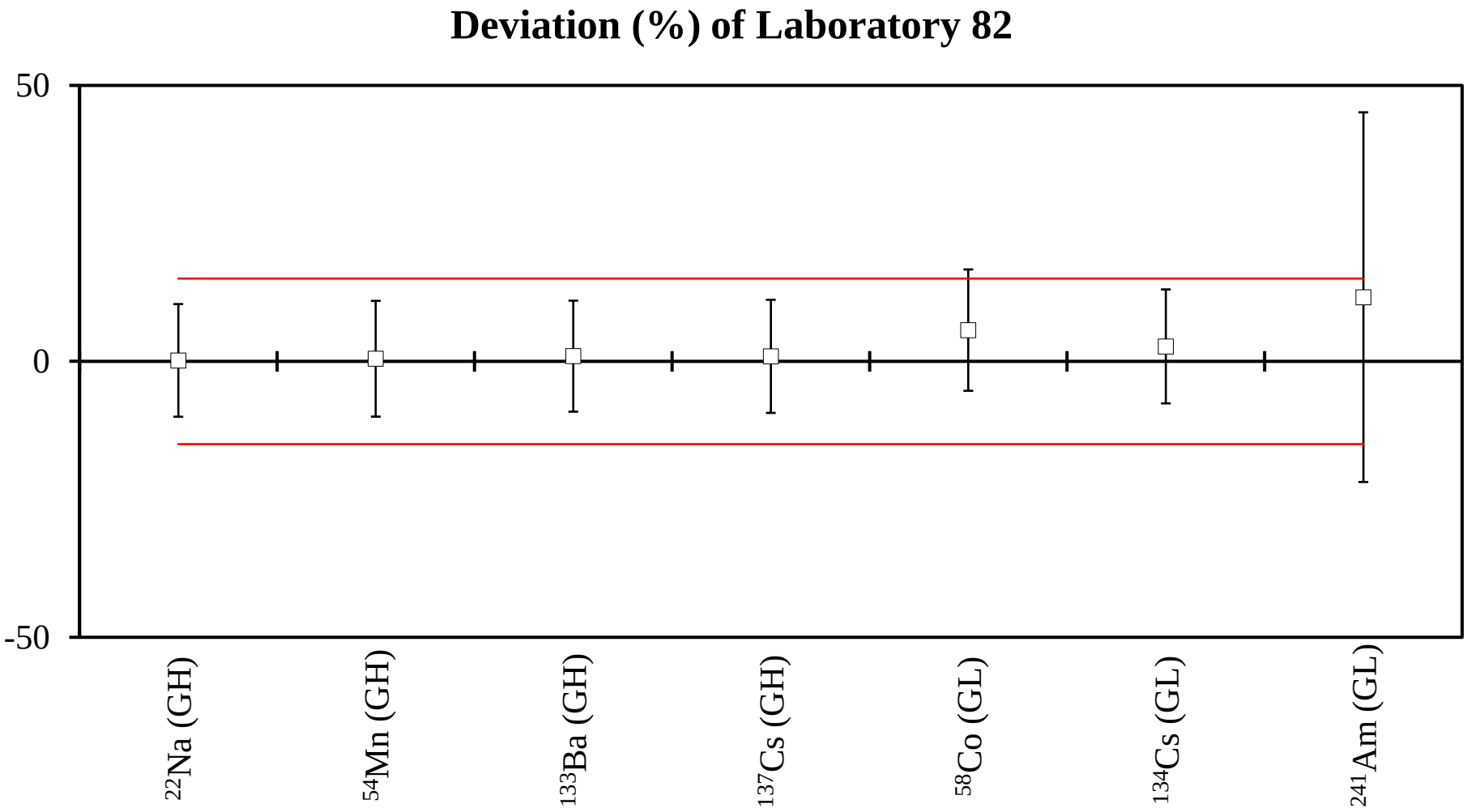
[2] Please note that the GL results from Laboratory 65 were entered into the reporting form incorrectly by the participants. The results inputted for GL were equivalent to the GH values. This was confirmed by Laboratory 65 to not be a measurement error and these results were excluded from calculation of participant summary data.


Deviation (%) of Laboratory 67
50
0
-50
22Na (GH)
54Mn (GH)
133Ba (GH)
137Cs (GH)

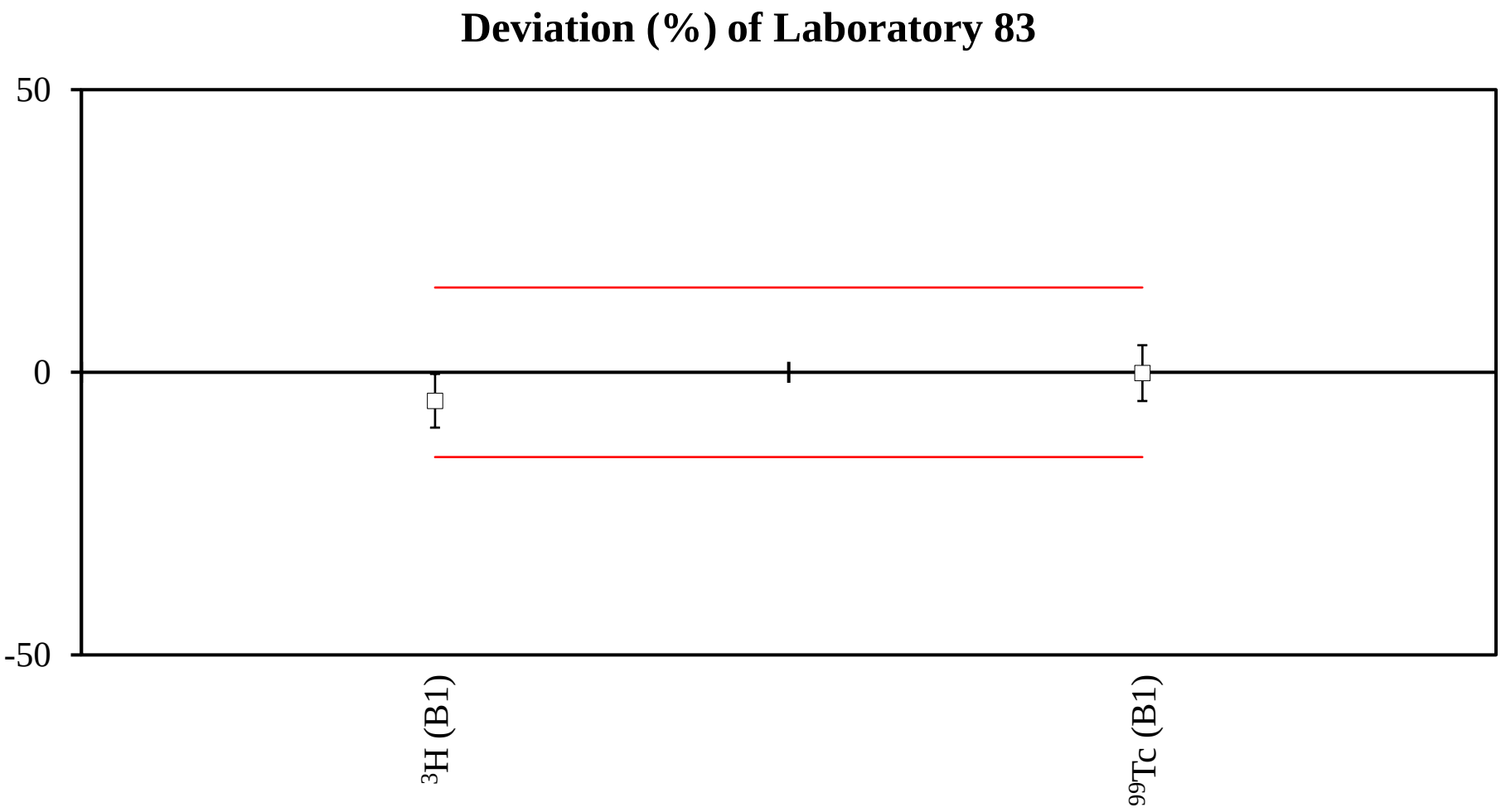
Radionuclide	Laboratory 67	NPL Assigned Value	Deviation (%)	Zeta	Z Score
^{22}Na (GH)	15.86 ± 0.81	16.672 ± 0.068	-4.9	-1.00	-0.84
^{54}Mn (GH)	11.12 ± 0.61	11.446 ± 0.043	-2.8	-0.53	-0.49
^{133}Ba (GH)	15.92 ± 0.88	16.94 ± 0.12	-6.0	-1.15	-1.03
^{137}Cs (GH)	8.38 ± 0.44	8.612 ± 0.064	-2.7	-0.52	-0.46


Deviation (%) of Laboratory 72
50
0
-50
3H (B1)
22Na (GH)
54Mn (GH)
133Ba (GH)
137Cs (GH)

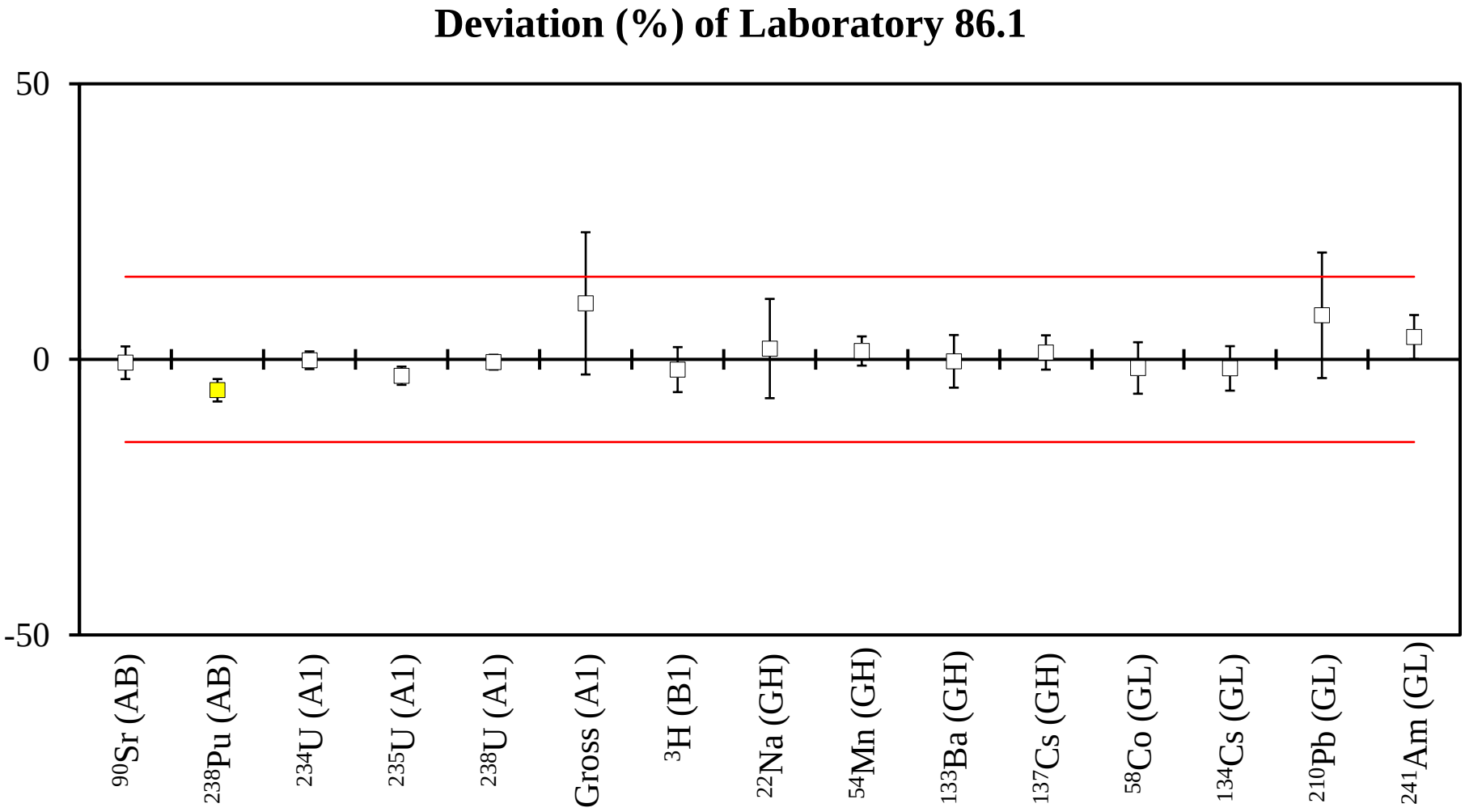
Radionuclide	Laboratory 72	NPL Assigned Value	Deviation (%)	Zeta	Z Score
^{3}H (B1)	0.568 ± 0.013	0.5655 ± 0.0071	0.4	0.17	0.08
^{22}Na (GH)	14.99 ± 0.69	16.672 ± 0.068	-10.1	-2.43	-1.73
^{54}Mn (GH)	12.42 ± 0.22	11.446 ± 0.043	8.5	4.35	1.46
^{133}Ba (GH)	15.82 ± 0.48	16.94 ± 0.12	-6.6	-2.26	-1.14
^{137}Cs (GH)	9.12 ± 0.19	8.612 ± 0.064	5.9	2.53	1.01


Deviation (%) of Laboratory 82
50
0
-50
^{22}Na (GH)
^{54}Mn (GH)
^{133}Ba (GH)
^{137}Cs (GH)
^{58}Co (GL)
^{134}Cs (GL)
^{241}Am (GL)

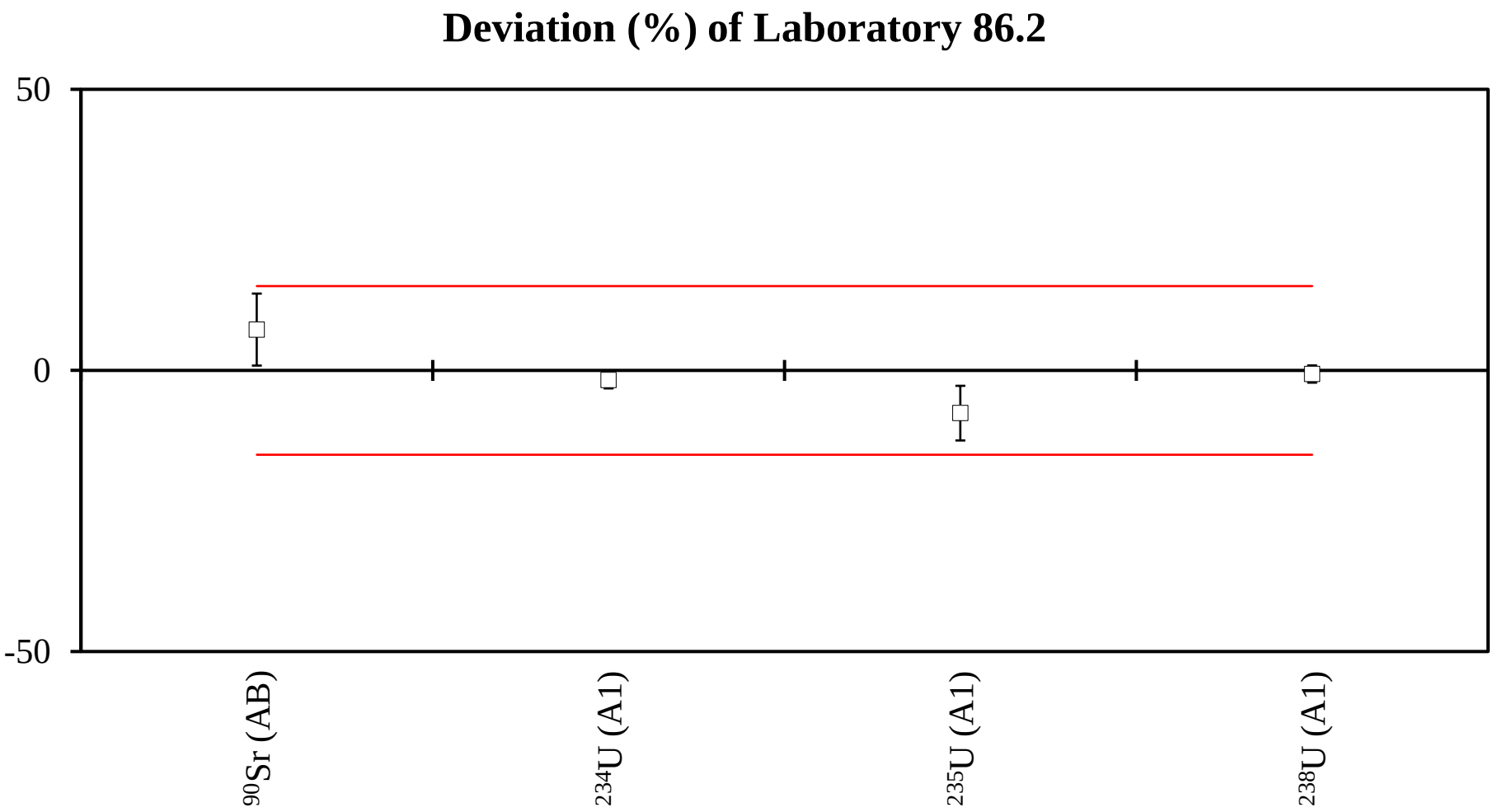
Radionuclide	Laboratory 82	NPL Assigned Value	Deviation (%)	Zeta	Z Score
^{22}Na (GH)	16.7 ± 1.7	16.672 ± 0.068	0.2	0.02	0.03
^{54}Mn (GH)	11.5 ± 1.2	11.446 ± 0.043	0.5	0.04	0.08
^{133}Ba (GH)	17.1 ± 1.7	16.94 ± 0.12	0.9	0.09	0.16
^{137}Cs (GH)	8.69 ± 0.88	8.612 ± 0.064	0.9	0.09	0.16
^{58}Co (GL)	36.6 ± 3.8	34.64 ± 0.24	5.7	0.51	0.97
^{134}Cs (GL)	20.1 ± 2.0	19.57 ± 0.28	2.7	0.26	0.47
^{241}Am (GL)	2.80 ± 0.84	2.5082 ± 0.0054	11.6	0.35	2.00


Deviation (%) of Laboratory 83
50
0
-50
^{3}H (B1)
^{99}Tc (B1)

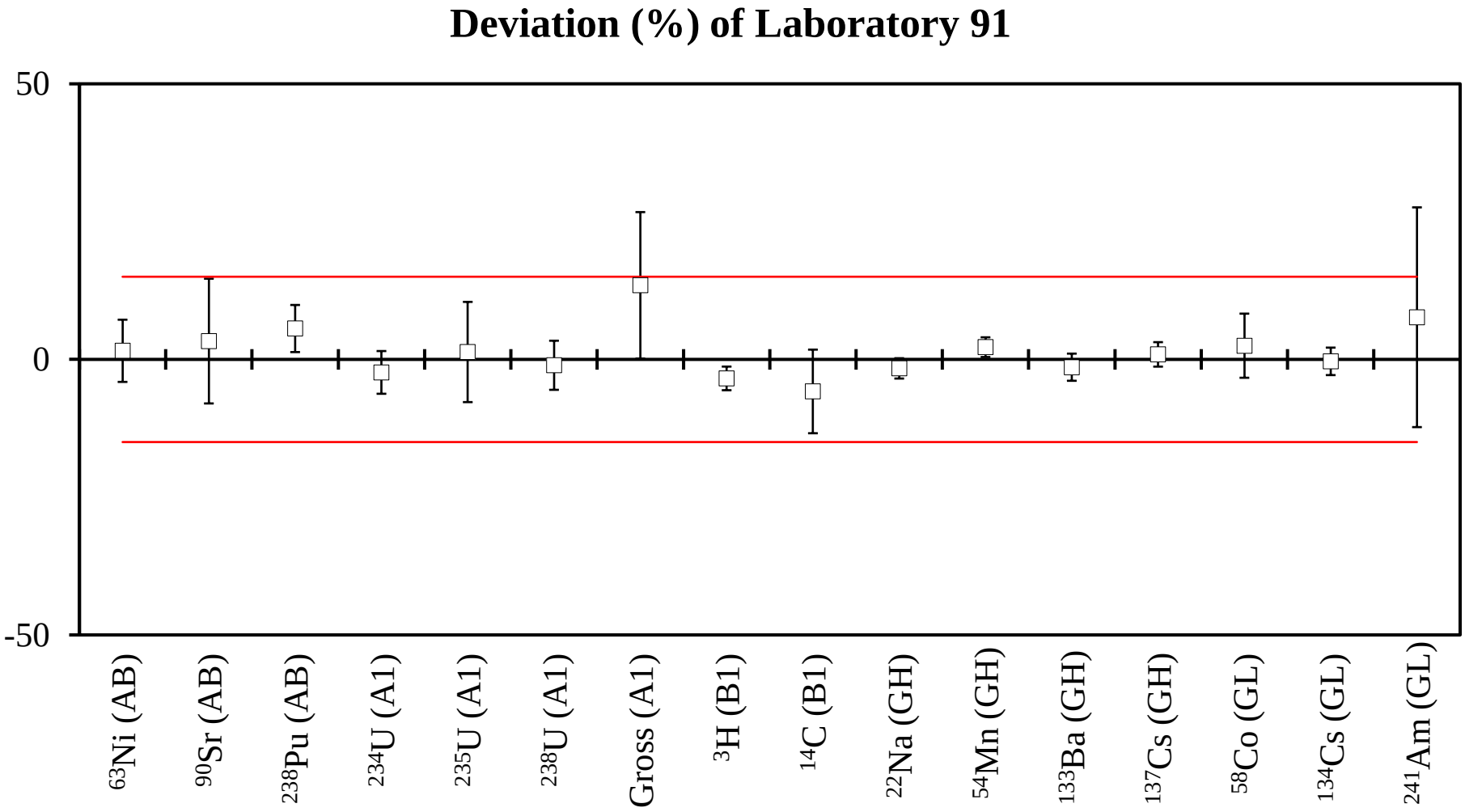
Radionuclide	Laboratory 83	NPL Assigned Value	Deviation (%)	Zeta	Z Score
^{3}H (B1)	0.537 ± 0.026	0.5655 ± 0.0071	-5.0	-1.06	-0.87
^{99}Tc (B1)	0.206 ± 0.010	0.2063 ± 0.0019	-0.1	-0.03	-0.02


Deviation (%) of Laboratory 86.1
50
0
-50
90Sr (AB)
238Pu (AB)
234U (A1)
235U (A1)
238U (A1)
Gross (A1)
3H (B1)
22Na (GH)
54Mn (GH)
133Ba (GH)
137Cs (GH)
58Co (GL)
134Cs (GL)
210Pb (GL)
241Am (GL)

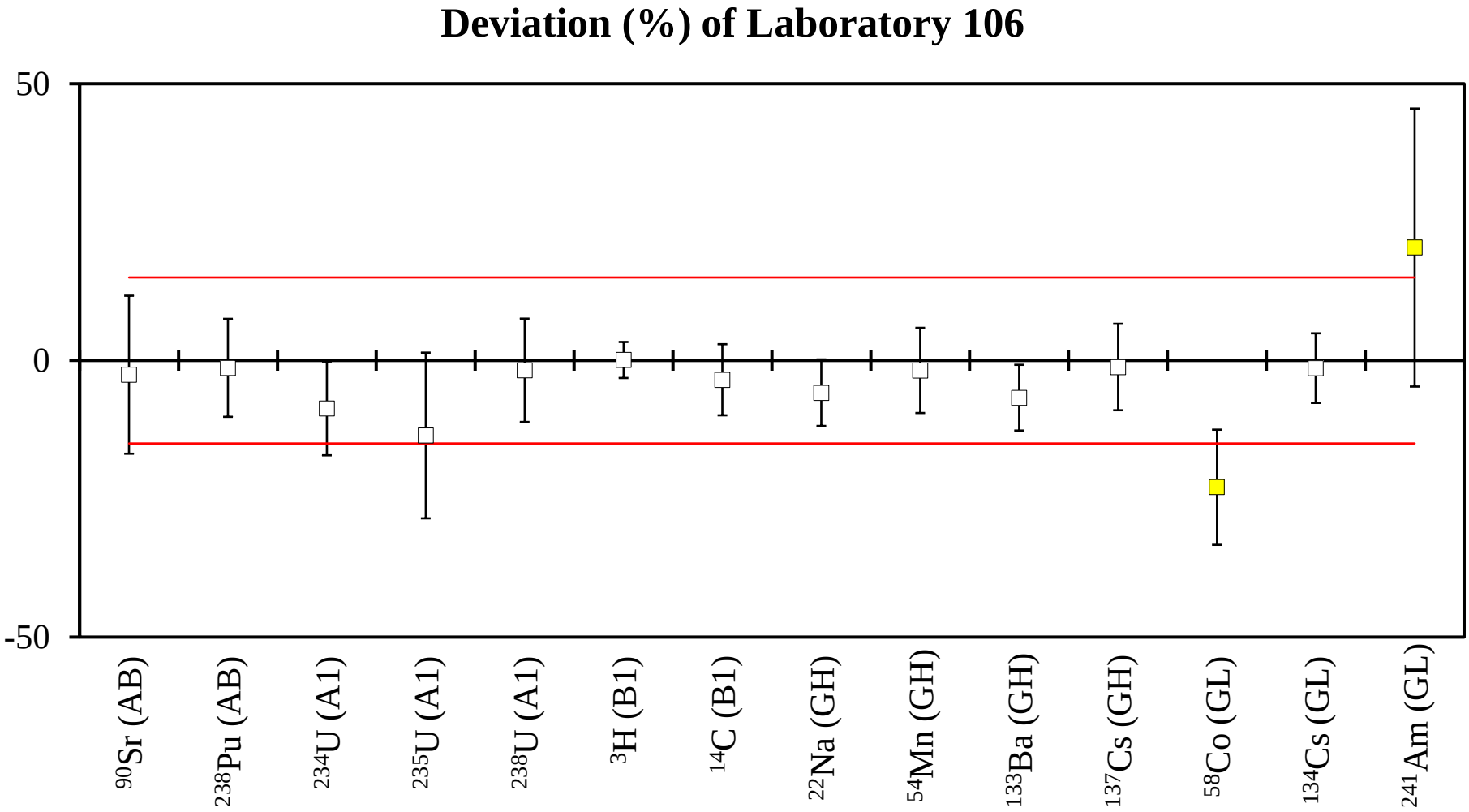
Radionuclide	Laboratory 86.1	NPL Assigned Value	Deviation (%)	Zeta	Z Score
^{90}Sr (AB)	2.02 ± 0.06	2.0324 ± 0.0054	-0.6	-0.21	-0.10
^{238}Pu (AB)	8.85 ± 0.19	9.375 ± 0.021	-5.6	-2.75	-0.96
^{234}U (A1)	19.02 ± 0.19	19.05 ± 0.24	-0.2	-0.10	-0.03
^{235}U (A1)	0.6511 ± 0.0030	0.671 ± 0.011	-3.0	-1.75	-0.51
^{238}U (A1)	13.978 ± 0.059	14.05 ± 0.18	-0.5	-0.38	-0.09
Gross alpha (A1)	33.6 ± 3.4	30.5 ± 1.8	10.2	0.81	1.75
^{3}H (B1)	0.555 ± 0.022	0.5655 ± 0.0071	-1.9	-0.45	-0.32
^{22}Na (GH)	17.0 ± 1.5	16.672 ± 0.068	2.0	0.22	0.34
^{54}Mn (GH)	11.620 ± 0.3	11.446 ± 0.043	1.5	0.57	0.26
^{133}Ba (GH)	16.88 ± 0.80	16.94 ± 0.12	-0.4	-0.07	-0.06
^{137}Cs (GH)	8.72 ± 0.26	8.612 ± 0.064	1.3	0.40	0.22
^{58}Co (GL)	34.1 ± 1.6	34.64 ± 0.24	-1.6	-0.33	-0.27
^{134}Cs (GL)	19.25 ± 0.74	19.57 ± 0.28	-1.6	-0.40	-0.28
^{210}Pb (GL)	16.2 ± 1.7	15.00 ± 0.16	8.0	0.70	1.37
^{241}Am (GL)	2.61 ± 0.10	2.5082 ± 0.0054	4.1	1.02	0.70


Deviation (%) of Laboratory 86.2
50
0
-50
90Sr (AB)
234U (A1)
235U (A1)
238U (A1)

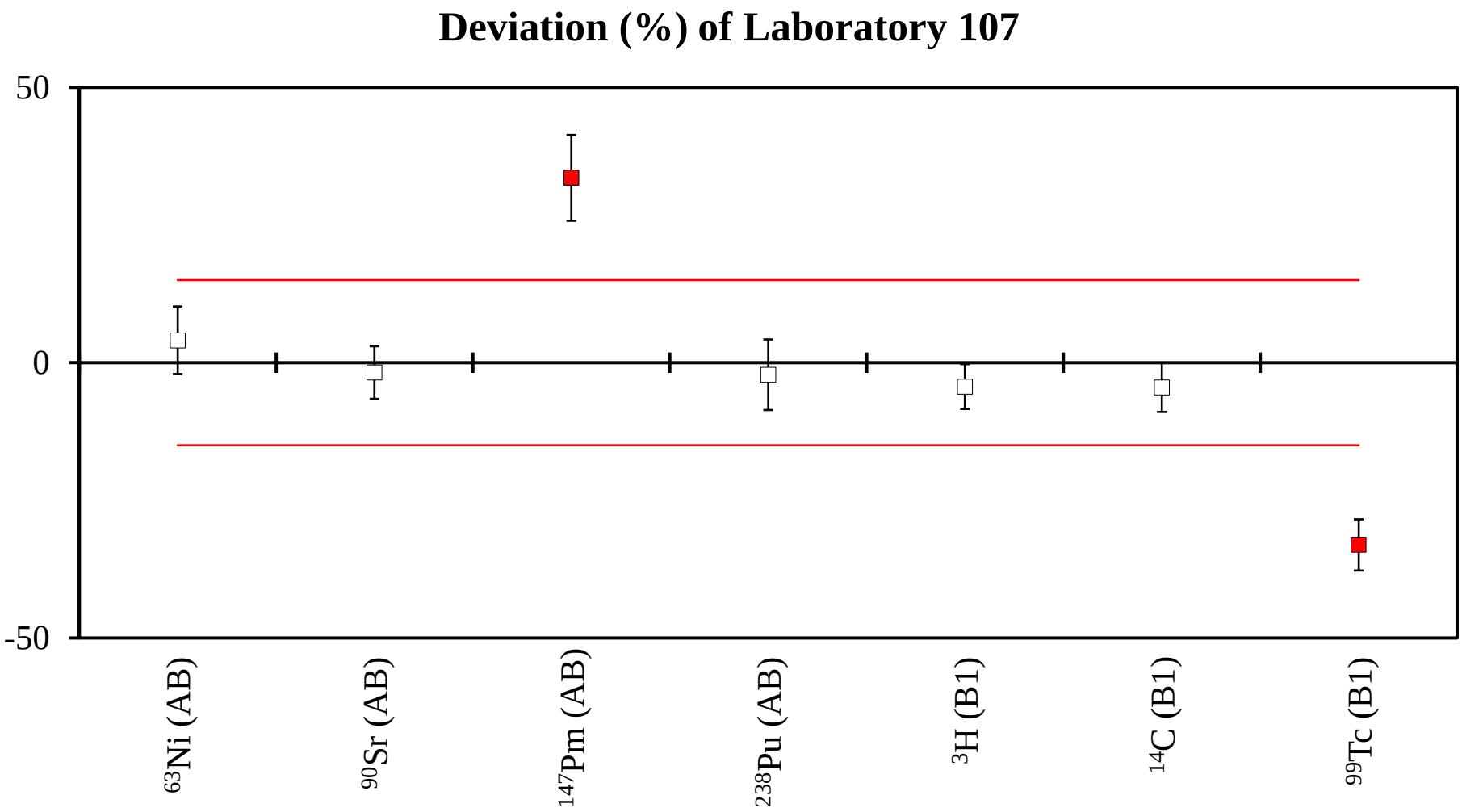
Radionuclide	Laboratory 86.2	NPL Assigned Value	Deviation (%)	Zeta	Z Score
^{90}Sr (AB)	2.18 ± 0.13	2.0324 ± 0.0054	7.3	1.13	1.25
^{234}U (A1)	18.72 ± 0.15	19.05 ± 0.24	-1.7	-1.17	-0.30
^{235}U (A1)	0.620 ± 0.031	0.671 ± 0.011	-7.6	-1.55	-1.31
^{238}U (A1)	13.96 ± 0.12	14.05 ± 0.18	-0.6	-0.42	-0.11


Deviation (%) of Laboratory 91
50
0
-50
63Ni (AB)
90Sr (AB)
238Pu (AB)
234U (A1)
235U (A1)
238U (A1)
Gross (A1)
3H (B1)
14C (B1)
22Na (GH)
54Mn (GH)
133Ba (GH)
137Cs (GH)
58Co (GL)
134Cs (GL)
241Am (GL)

Radionuclide	Laboratory 91	NPL Assigned Value	Deviation (%)	Zeta	Z Score
^{63}Ni (AB)	2.02 ± 0.11	1.989 ± 0.022	1.6	0.28	0.27
^{90}Sr (AB)	2.10 ± 0.23	2.0324 ± 0.0054	3.3	0.29	0.57
^{238}Pu (AB)	9.90 ± 0.40	9.375 ± 0.021	5.6	1.31	0.96
^{234}U (A1)	18.6 ± 0.7	19.05 ± 0.24	-2.4	-0.61	-0.41
^{235}U (A1)	0.68 ± 0.06	0.671 ± 0.011	1.3	0.15	0.23
^{238}U (A1)	13.9 ± 0.6	14.05 ± 0.18	-1.1	-0.24	-0.18
Gross alpha (A1)	34.6 ± 3.5	30.5 ± 1.8	13.4	1.04	2.31
^{3}H (B1)	0.546 ± 0.010	0.5655 ± 0.0071	-3.4	-1.59	-0.59
^{14}C (B1)	0.162 ± 0.013	0.1720 ± 0.0012	-5.8	-0.77	-1.00
^{22}Na (GH)	16.4 ± 0.3	16.672 ± 0.068	-1.6	-0.88	-0.28
^{54}Mn (GH)	11.70 ± 0.20	11.446 ± 0.043	2.2	1.24	0.38
^{133}Ba (GH)	16.70 ± 0.40	16.94 ± 0.12	-1.4	-0.57	-0.24
^{137}Cs (GH)	8.69 ± 0.18	8.612 ± 0.064	0.9	0.41	0.16
^{58}Co (GL)	35.5 ± 2.0	34.64 ± 0.24	2.5	0.43	0.43
^{134}Cs (GL)	19.50 ± 0.40	19.57 ± 0.28	-0.4	-0.14	-0.06
^{241}Am (GL)	2.70 ± 0.50	2.5082 ± 0.0054	7.6	0.38	1.31

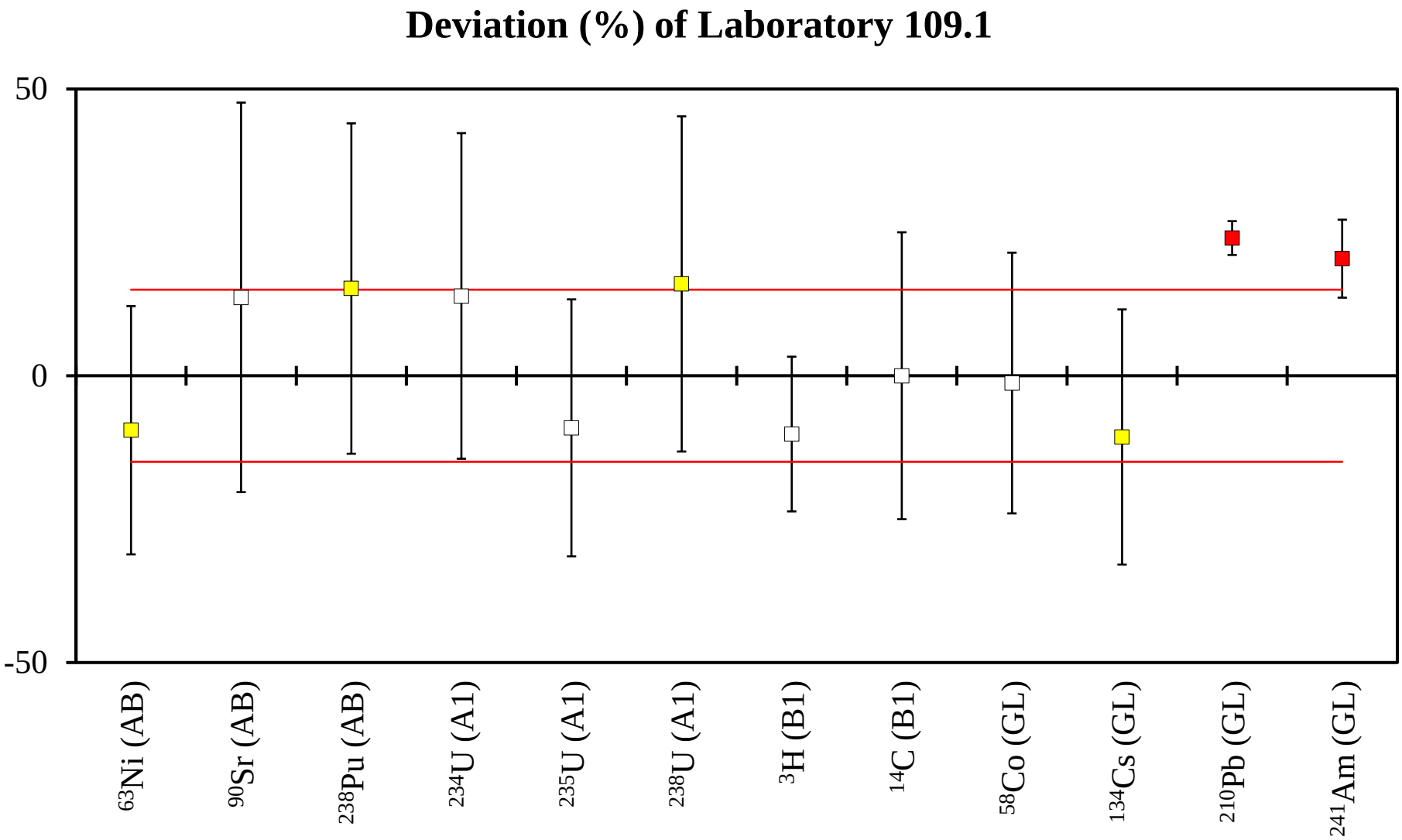

Deviation (%) of Laboratory 106
50
0
-50
90Sr (AB)
238Pu (AB)
234U (A1)
235U (A1)
238U (A1)
3H (B1)
14C (B1)
22Na (GH)
54Mn (GH)
133Ba (GH)
137Cs (GH)
58Co (GL)
134Cs (GL)
241Am (GL)

Radionuclide	Laboratory 106	NPL Assigned Value	Deviation (%)	Zeta	Z Score
^{90}Sr (AB)	1.98 ± 0.29	2.0324 ± 0.0054	-2.6	-0.18	-0.44
^{238}Pu (AB)	9.25 ± 0.83	9.375 ± 0.021	-1.3	-0.15	-0.23
^{234}U (A1)	17.4 ± 1.6	19.05 ± 0.24	-8.7	-1.02	-1.49
^{235}U (A1)	0.58 ± 0.10	0.671 ± 0.011	-13.6	-0.90	-2.33
^{238}U (A1)	13.8 ± 1.3	14.05 ± 0.18	-1.8	-0.19	-0.31
^{3}H (B1)	0.566 ± 0.017	0.5655 ± 0.0071	0.1	0.03	0.02
^{14}C (B1)	0.166 ± 0.011	0.1720 ± 0.0012	-3.5	-0.54	-0.60
^{22}Na (GH)	15.7 ± 1.0	16.672 ± 0.068	-5.8	-0.97	-1.00
^{54}Mn (GH)	11.24 ± 0.88	11.446 ± 0.043	-1.8	-0.23	-0.31
^{133}Ba (GH)	15.8 ± 1.0	16.94 ± 0.12	-6.7	-1.13	-1.16
^{137}Cs (GH)	8.51 ± 0.67	8.612 ± 0.064	-1.2	-0.15	-0.20
^{58}Co (GL)	26.7 ± 3.6	34.64 ± 0.24	-22.9	-2.20	-3.94
^{134}Cs (GL)	19.3 ± 1.2	19.57 ± 0.28	-1.4	-0.22	-0.24
^{241}Am (GL)	3.02 ± 0.63	2.5082 ± 0.0054	20.4	0.81	3.50

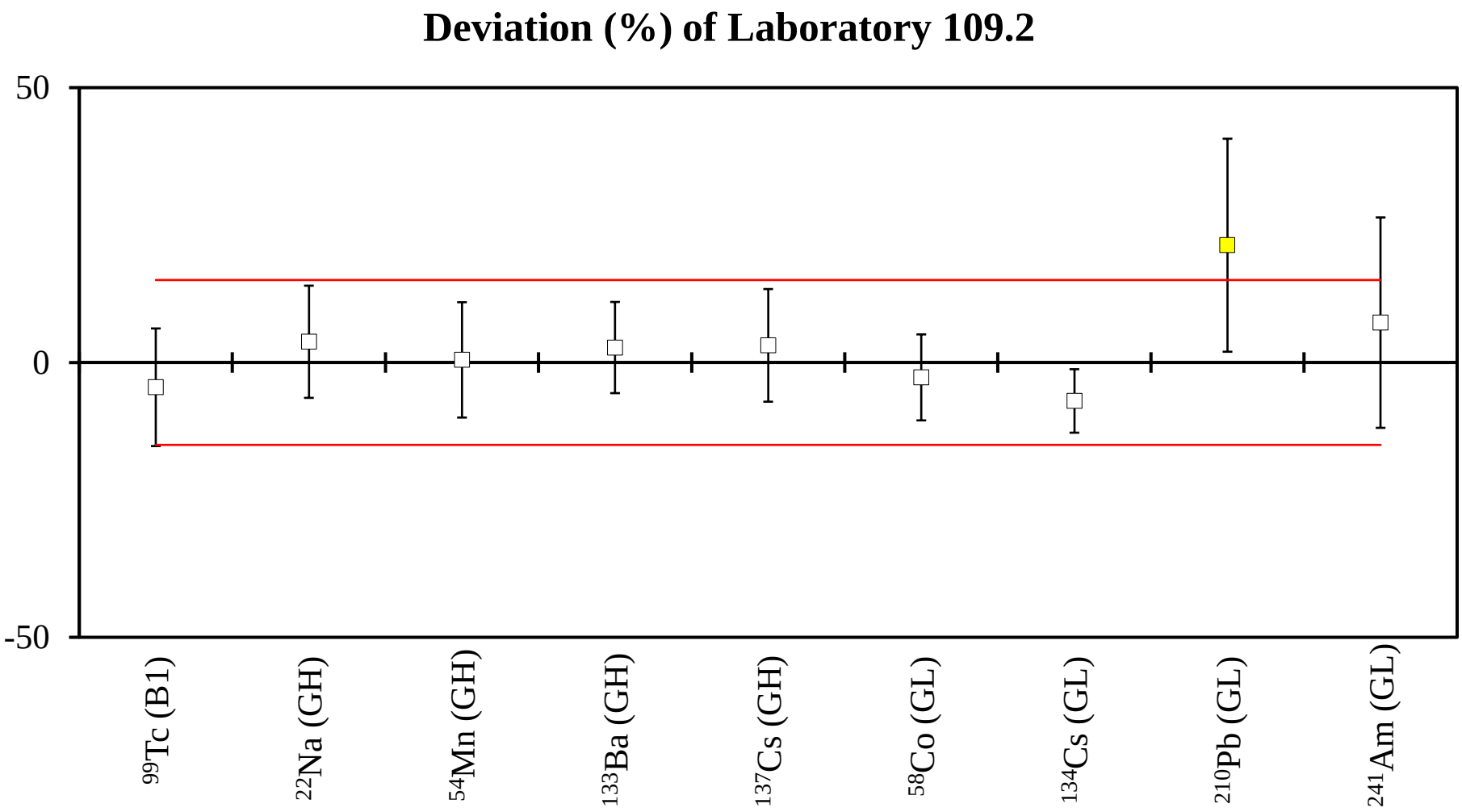

Deviation (%) of Laboratory 107
50
0
-50
63Ni (AB)
90Sr (AB)
147Pm (AB)
238Pu (AB)
3H (B1)
14C (B1)
99Tc (B1)

Radionuclide	Laboratory 107	NPL Assigned Value	Deviation (%)	Zeta	Z Score
^{63}Ni (AB)	2.07 ± 0.12	1.989 ± 0.022	4.1	0.66	0.70
^{90}Sr (AB)	1.996 ± 0.097	2.0324 ± 0.0054	-1.8	-0.37	-0.31
^{147}Pm (AB)	22.6 ± 1.3	16.92 ± 0.16	33.6	4.34	5.77
^{238}Pu (AB)	9.170 ± 0.6	9.375 ± 0.021	-2.2	-0.34	-0.38
^{3}H (B1)	0.541 ± 0.022	0.5655 ± 0.0071	-4.3	-1.06	-0.74
^{14}C (B1)	0.1643 ± 0.0076	0.1720 ± 0.0012	-4.5	-1.00	-0.77
^{99}Tc (B1)[3]	0.1380 ± 0.0095	0.2063 ± 0.0019	-33.1	-7.05	-5.69

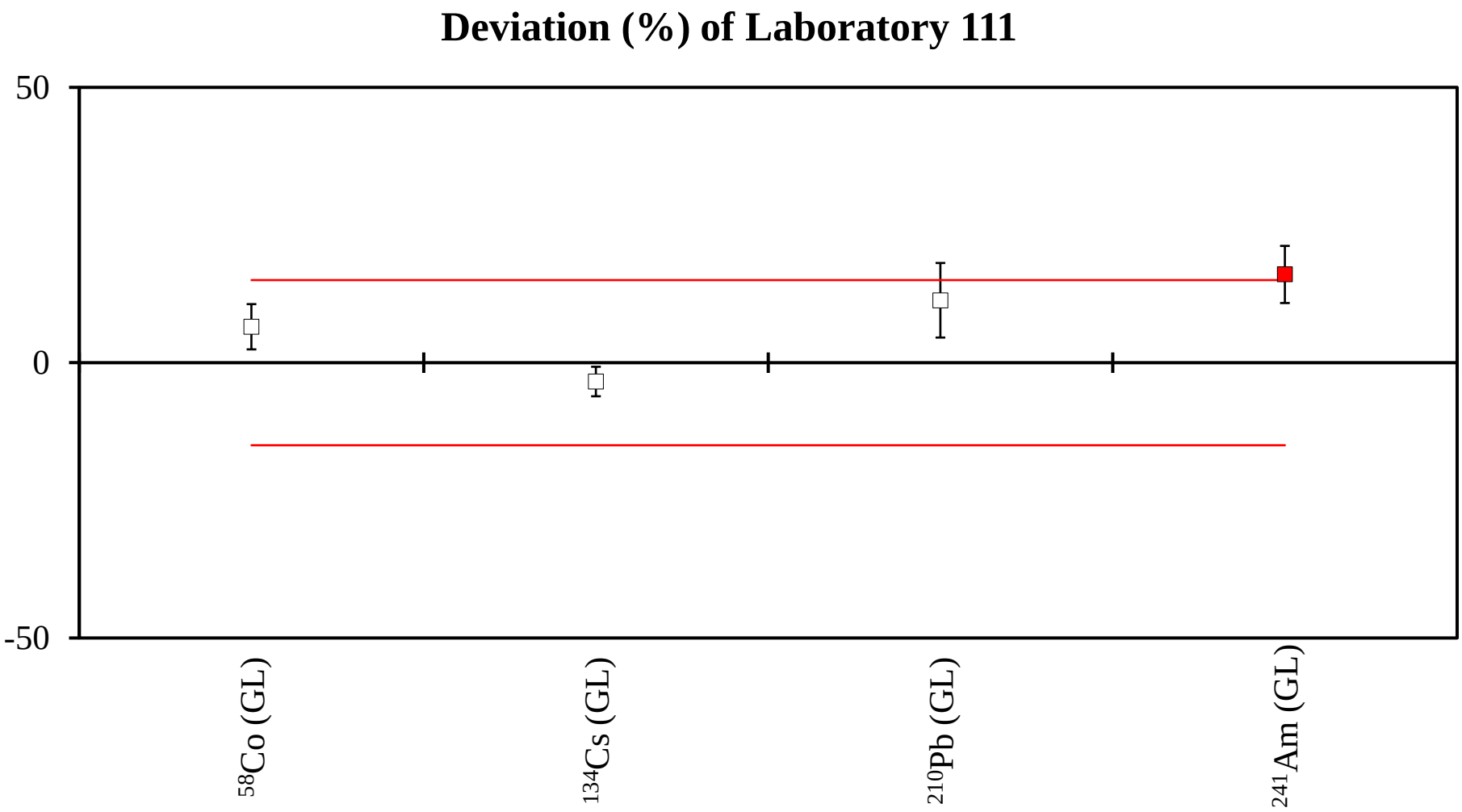
[3] Please note that the ^{99}Tc result for Laboratory 107 was a reporting error. As this was not a measurement error these results were not used during the summary of participant results.


Deviation (%) of Laboratory 109.1
50
0
-50
63Ni (AB)
90Sr (AB)
238Pu (AB)
234U (A1)
235U (A1)
238U (A1)
3H (B1)
14C (B1)
58Co (GL)
134Cs (GL)
210Pb (GL)
241Am (GL)

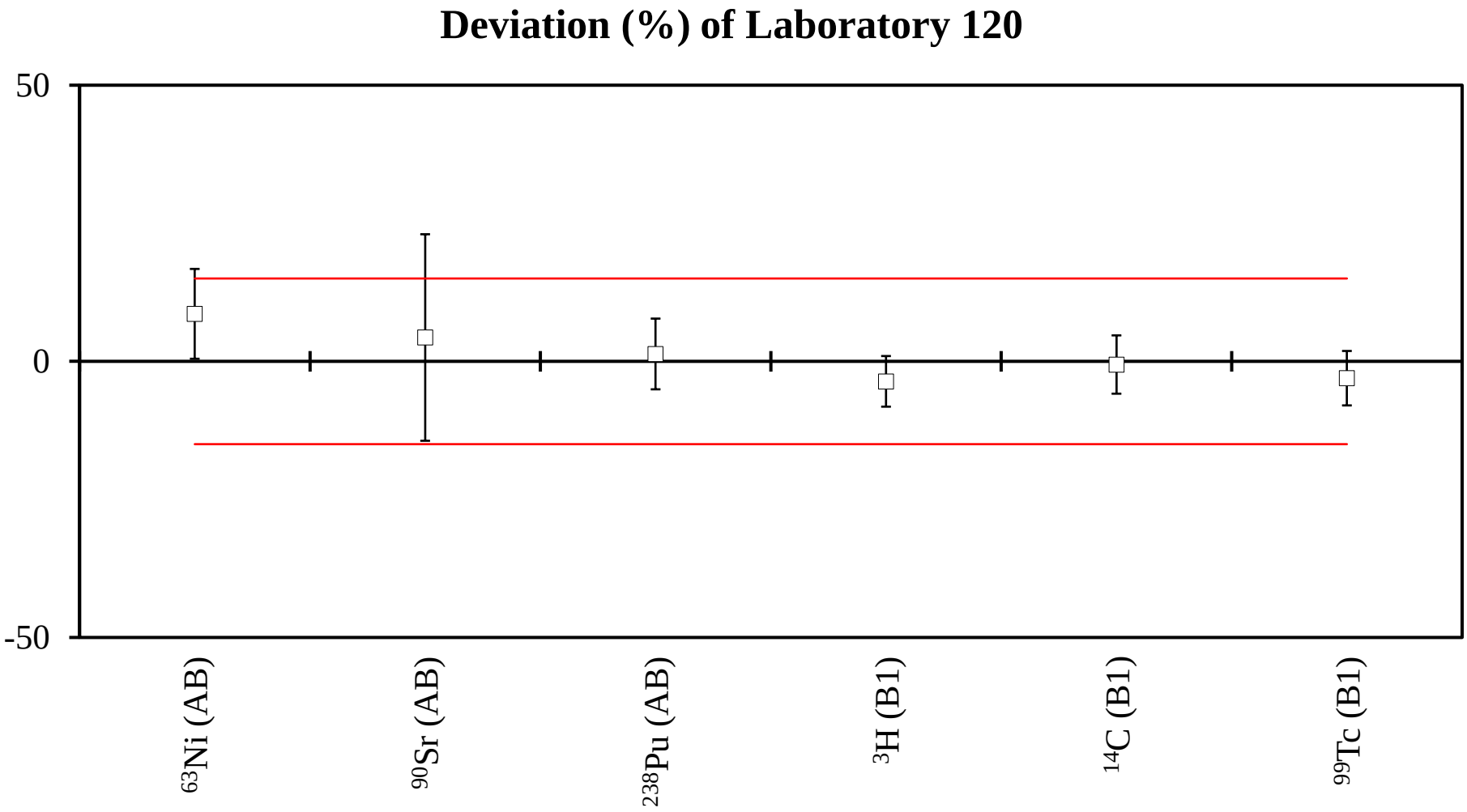
Radionuclide	Laboratory 109.1	NPL Assigned Value	Deviation (%)	Zeta	Z Score
^{63}Ni (AB)	1.80 ± 0.43	1.989 ± 0.022	-9.5	-0.44	-1.63
^{90}Sr (AB)	2.31 ± 0.69	2.0324 ± 0.0054	13.7	0.40	2.35
^{238}Pu (AB)	10.8 ± 2.7	9.375 ± 0.021	15.2	0.53	2.61
^{234}U (A1)	21.7 ± 5.4	19.05 ± 0.24	13.9	0.49	2.39
^{235}U (A1)	0.61 ± 0.15	0.671 ± 0.011	-9.1	-0.41	-1.56
^{238}U (A1)	16.3 ± 4.1	14.05 ± 0.18	16.0	0.55	2.75
^{3}H (B1)	0.508 ± 0.076	0.5655 ± 0.0071	-10.2	-0.75	-1.75
^{14}C (B1)	0.172 ± 0.043	0.1720 ± 0.0012	0.0	0.00	0.00
Gross beta (B1)	0.352 ± 0.053	-	-	-	-
^{58}Co (GL)	34.2 ± 7.7	34.64 ± 0.24	-1.3	-0.06	-0.22
^{134}Cs (GL)	17.48 ± 0.52	19.57 ± 0.28	-10.7	-3.54	-1.83
^{210}Pb (GL)	18.6 ± 1.0	15.00 ± 0.16	24.0	3.55	4.12
^{241}Am (GL)	3.02 ± 0.17	2.5082 ± 0.0054	20.4	3.01	3.50


Deviation (%) of Laboratory 109.2
50
0
-50
99Tc (B1)
22Na (GH)
54Mn (GH)
133Ba (GH)
137Cs (GH)
58Co (GL)
134Cs (GL)
210Pb (GL)
241Am (GL)

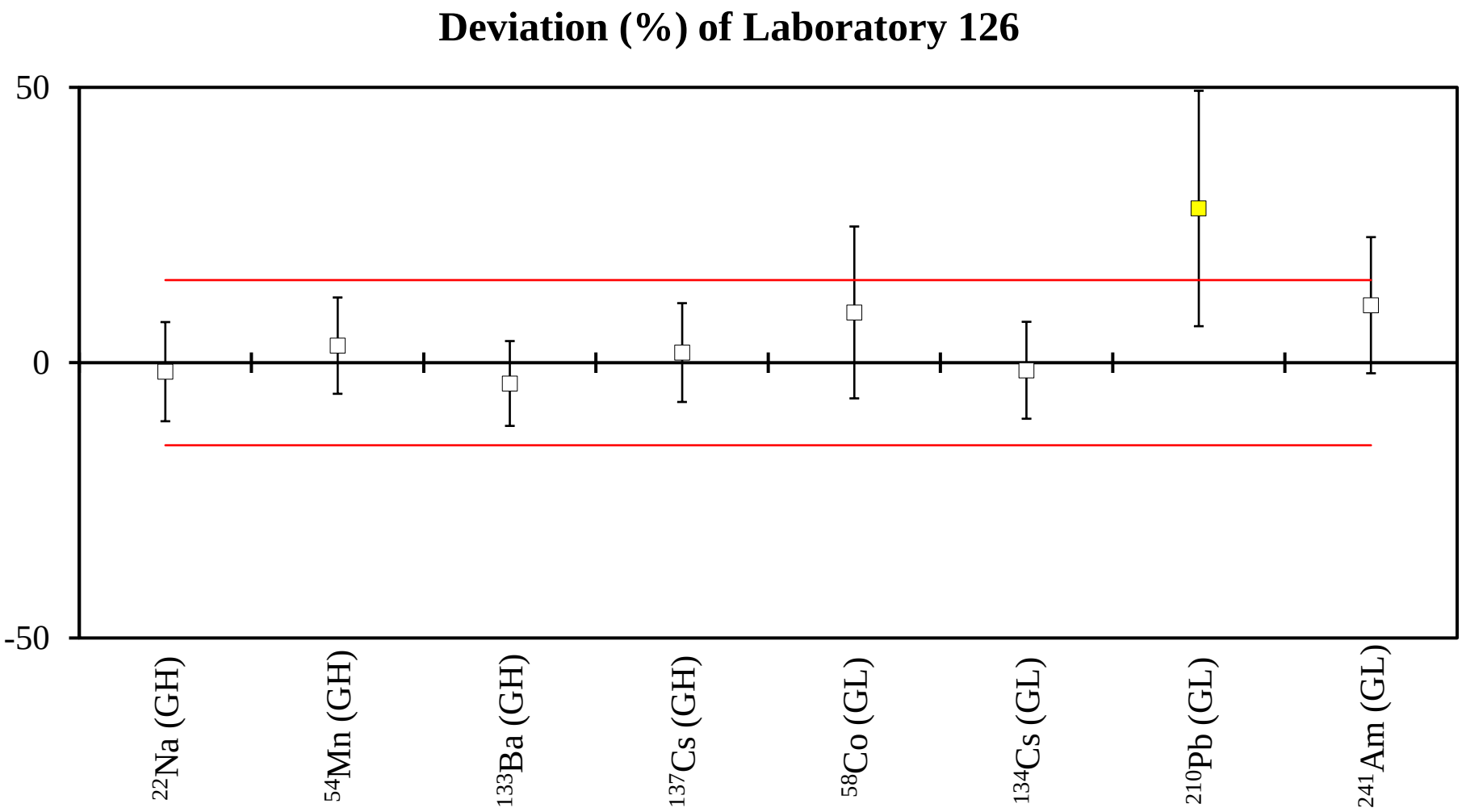
Radionuclide	Laboratory 109.2	NPL Assigned Value	Deviation (%)	Zeta	Z Score
^{99}Tc (B1)	0.197 ± 0.022	0.2063 ± 0.0019	-4.5	-0.42	-0.77
^{22}Na (GH)	17.3 ± 1.7	16.672 ± 0.068	3.8	0.37	0.65
^{54}Mn (GH)	11.5 ± 1.2	11.446 ± 0.043	0.5	0.04	0.08
^{133}Ba (GH)	17.4 ± 1.4	16.94 ± 0.12	2.7	0.33	0.47
^{137}Cs (GH)	8.88 ± 0.88	8.612 ± 0.064	3.1	0.30	0.53
^{58}Co (GL)	33.7 ± 2.7	34.64 ± 0.24	-2.7	-0.35	-0.47
^{134}Cs (GL)	18.2 ± 1.1	19.57 ± 0.28	-7.0	-1.21	-1.20
^{210}Pb (GL)	18.2 ± 2.9	15.00 ± 0.16	21.3	1.10	3.66
^{241}Am (GL)	2.69 ± 0.48	2.5082 ± 0.0054	7.2	0.38	1.24


Deviation (%) of Laboratory 111
50
0
-50
58Co (GL)
134Cs (GL)
210Pb (GL)
241Am (GL)

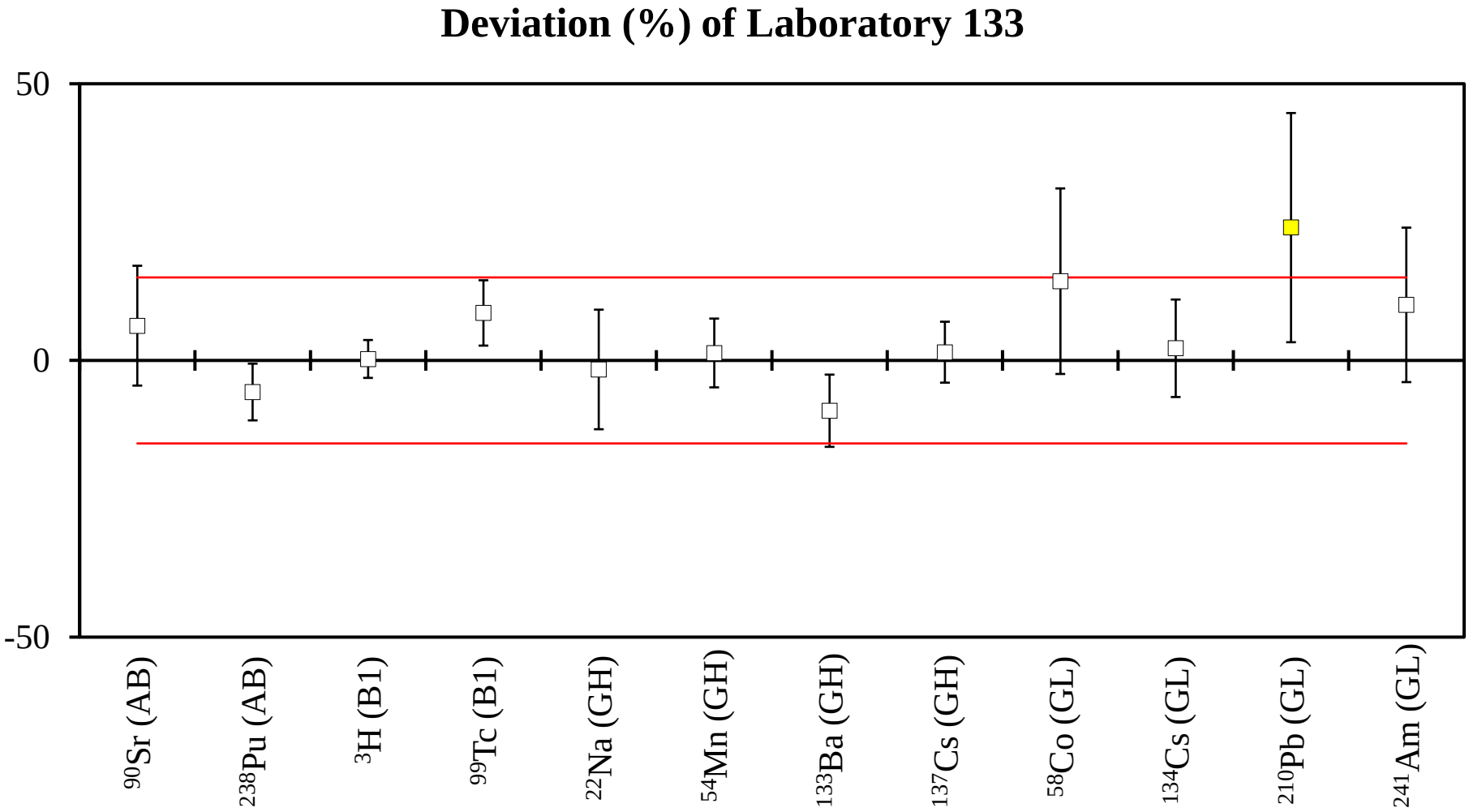
Radionuclide	Laboratory 111	NPL Assigned Value	Deviation (%)	Zeta	Z Score
^{58}Co (GL)	36.9 ± 1.4	34.64 ± 0.24	6.5	1.59	1.12
^{134}Cs (GL)	18.90 ± 0.45	19.57 ± 0.28	-3.4	-1.26	-0.59
^{210}Pb (GL)	16.7 ± 1.0	15.00 ± 0.16	11.3	1.68	1.95
^{241}Am (GL)	2.91 ± 0.13	2.5082 ± 0.0054	16.0	3.09	2.75


Deviation (%) of Laboratory 120
50
0
-50
63Ni (AB)
90Sr (AB)
238Pu (AB)
3H (B1)
14C (B1)
99Tc (B1)

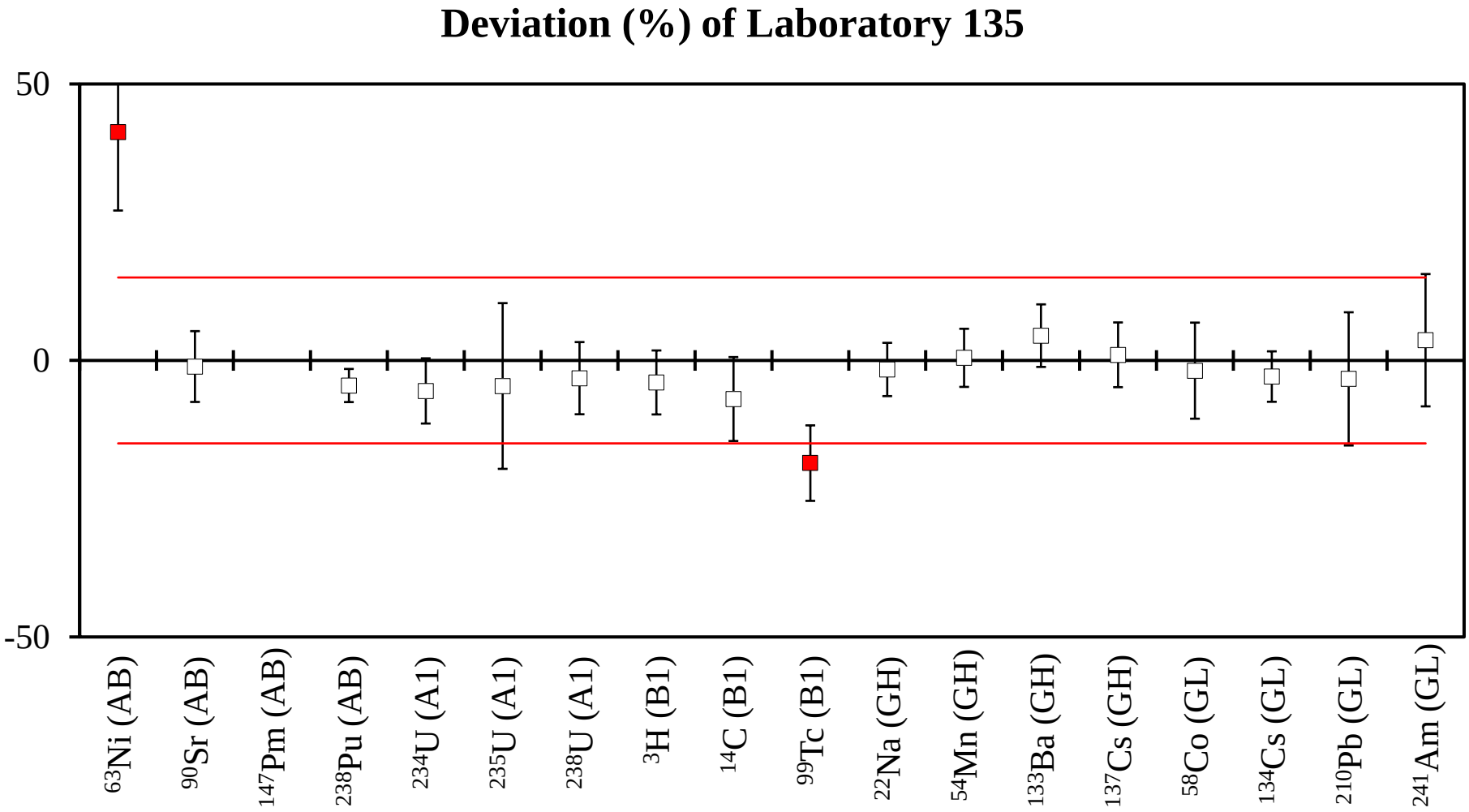
Radionuclide	Laboratory 120	NPL Assigned Value	Deviation (%)	Zeta	Z Score
^{63}Ni (AB)	2.16 ± 0.16	1.989 ± 0.022	8.6	1.06	1.48
^{90}Sr (AB)	2.12 ± 0.38	2.0324 ± 0.0054	4.3	0.23	0.74
^{238}Pu (AB)	9.5 ± 0.6	9.375 ± 0.021	1.3	0.21	0.23
^{3}H (B1)	0.545 ± 0.025	0.5655 ± 0.0071	-3.6	-0.79	-0.62
^{14}C (B1)	0.171 ± 0.009	0.1720 ± 0.0012	-0.6	-0.11	-0.10
^{99}Tc (B1)	0.200 ± 0.010	0.2063 ± 0.0019	-3.1	-0.62	-0.52


Deviation (%) of Laboratory 126
50
0
-50
^{22}Na (GH)
^{54}Mn (GH)
^{133}Ba (GH)
^{137}Cs (GH)
^{58}Co (GL)
^{134}Cs (GL)
^{210}Pb (GL)
^{241}Am (GL)

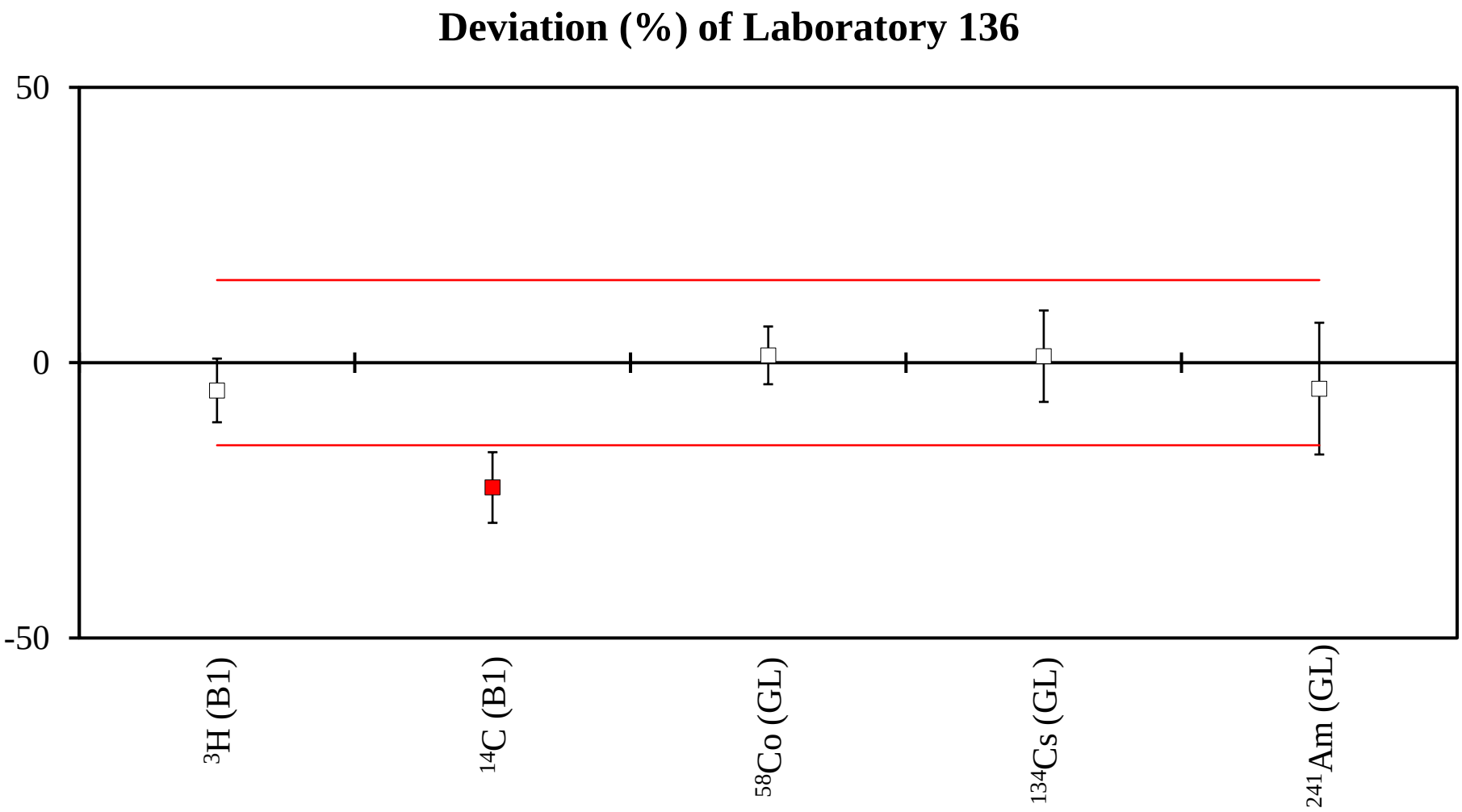
Radionuclide	Laboratory 126	NPL Assigned Value	Deviation (%)	Zeta	Z Score
^{22}Na (GH)	16.4 ± 1.5	16.672 ± 0.068	-1.6	-0.18	-0.28
^{54}Mn (GH)	11.8 ± 1.0	11.446 ± 0.043	3.1	0.35	0.53
^{133}Ba (GH)	16.3 ± 1.3	16.94 ± 0.12	-3.8	-0.49	-0.65
^{137}Cs (GH)	8.77 ± 0.77	8.612 ± 0.064	1.8	0.20	0.32
^{58}Co (GL)	37.8 ± 5.4	34.64 ± 0.24	9.1	0.58	1.57
^{134}Cs (GL)	19.3 ± 1.7	19.57 ± 0.28	-1.4	-0.16	-0.24
^{210}Pb (GL)	19.2 ± 3.2	15.00 ± 0.16	28.0	1.31	4.81
^{241}Am (GL)	2.77 ± 0.31	2.5082 ± 0.0054	10.4	0.84	1.79


Deviation (%) of Laboratory 133
50
0
-50
^{90}Sr (AB)
^{238}Pu (AB)
^{3}H (B1)
^{99}Tc (B1)
^{22}Na (GH)
^{54}Mn (GH)
^{133}Ba (GH)
^{137}Cs (GH)
^{58}Co (GL)
^{134}Cs (GL)
^{210}Pb (GL)
^{241}Am (GL)

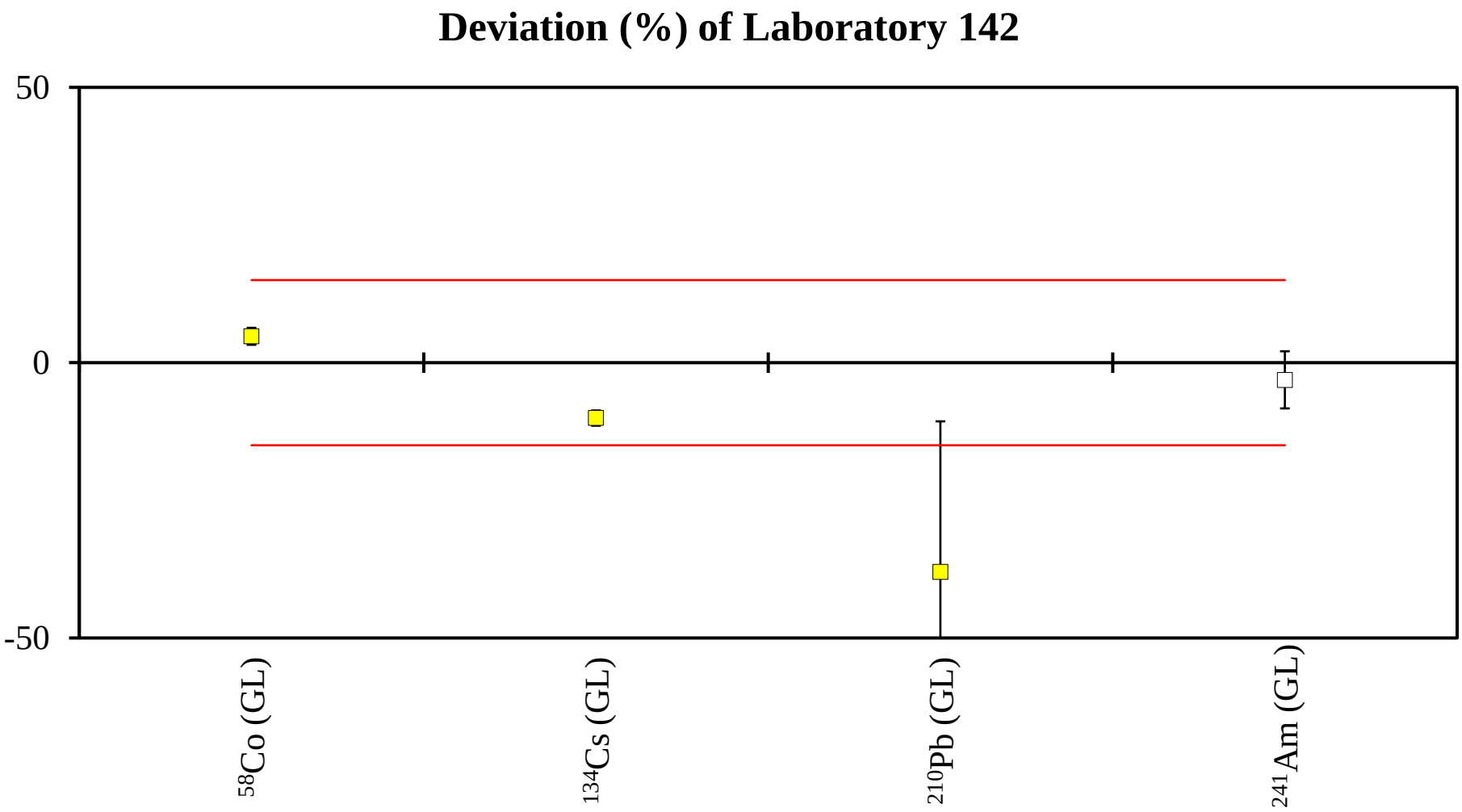
Radionuclide	Laboratory 133	NPL Assigned Value	Deviation (%)	Zeta	Z Score
^{90}Sr (AB)	2.16 ± 0.22	2.0324 ± 0.0054	6.3	0.58	1.08
^{238}Pu (AB)	8.84 ± 0.48	9.375 ± 0.021	-5.7	-1.11	-0.98
^{3}H (B1)	0.567 ± 0.018	0.5655 ± 0.0071	0.3	0.08	0.05
^{99}Tc (B1)	0.224 ± 0.012	0.2063 ± 0.0019	8.6	1.46	1.47
^{22}Na (GH)	16.4 ± 1.8	16.672 ± 0.068	-1.6	-0.15	-0.28
^{54}Mn (GH)	11.60 ± 0.71	11.446 ± 0.043	1.3	0.22	0.23
^{133}Ba (GH)	15.4 ± 1.1	16.94 ± 0.12	-9.1	-1.39	-1.56
^{137}Cs (GH)	8.74 ± 0.47	8.612 ± 0.064	1.5	0.27	0.26
^{58}Co (GL)	39.6 ± 5.8	34.64 ± 0.24	14.3	0.85	2.46
^{134}Cs (GL)	20.0 ± 1.7	19.57 ± 0.28	2.2	0.25	0.38
^{210}Pb (GL)	18.6 ± 3.1	15.00 ± 0.16	24.0	1.16	4.12
^{241}Am (GL)	2.76 ± 0.35	2.5082 ± 0.0054	10.0	0.72	1.72


Deviation (%) of Laboratory 135
50
0
-50
63Ni (AB)
90Sr (AB)
147Pm (AB)
238Pu (AB)
234U (A1)
235U (A1)
238U (A1)
3H (B1)
14C (B1)
99Tc (B1)
22Na (GH)
54Mn (GH)
133Ba (GH)
137Cs (GH)
58Co (GL)
134Cs (GL)
210Pb (GL)
241Am (GL)

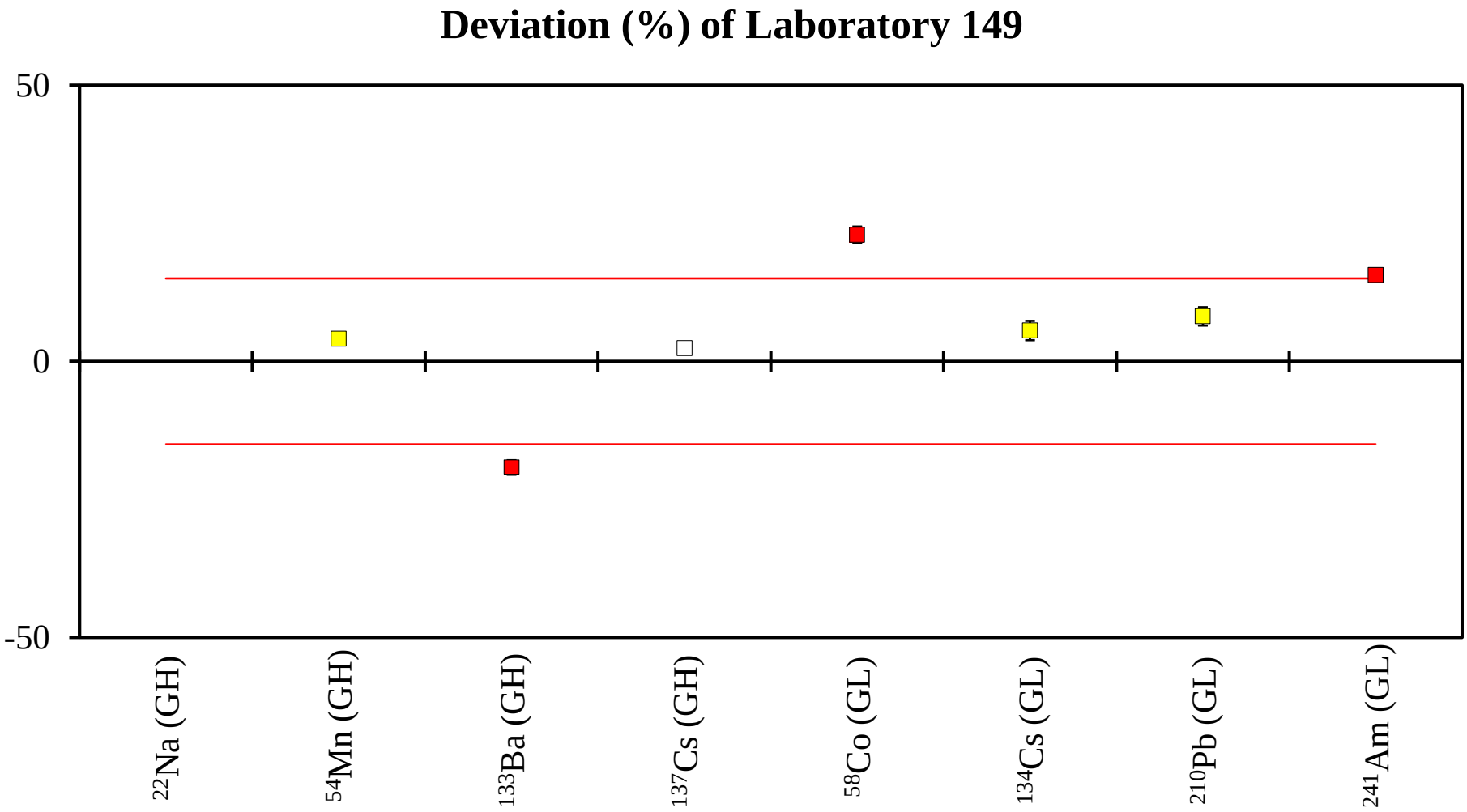
Radionuclide	Laboratory 135	NPL Assigned Value	Deviation (%)	Zeta	Z Score
^{63}Ni (AB)	2.81 ± 0.28	1.989 ± 0.022	41.3	2.92	7.09
^{90}Sr (AB)	2.01 ± 0.13	2.0324 ± 0.0054	-1.1	-0.17	-0.19
^{147}Pm (AB)	4.80 ± 0.96	16.92 ± 0.16	-71.6	-12.45	-12.30
^{238}Pu (AB)	8.95 ± 0.28	9.375 ± 0.021	-4.5	-1.51	-0.78
^{234}U (A1)	18.0 ± 1.1	19.05 ± 0.24	-5.5	-0.93	-0.95
^{235}U (A1)	0.64 ± 0.10	0.671 ± 0.011	-4.6	-0.31	-0.79
^{238}U (A1)	13.60 ± 0.90	14.05 ± 0.18	-3.2	-0.49	-0.55
^{3}H (B1)	0.543 ± 0.032	0.5655 ± 0.0071	-4.0	-0.69	-0.68
^{14}C (B1)	0.160 ± 0.013	0.1720 ± 0.0012	-7.0	-0.92	-1.20
^{99}Tc (B1)	0.168 ± 0.014	0.2063 ± 0.0019	-18.6	-2.71	-3.19
^{22}Na (GH)	16.40 ± 0.80	16.672 ± 0.068	-1.6	-0.34	-0.28
^{54}Mn (GH)	11.5 ± 0.6	11.446 ± 0.043	0.5	0.09	0.08
^{133}Ba (GH)	17.70 ± 0.95	16.94 ± 0.12	4.5	0.79	0.77
^{137}Cs (GH)	8.70 ± 0.50	8.612 ± 0.064	1.0	0.17	0.18
^{58}Co (GL)	34.0 ± 3.0	34.64 ± 0.24	-1.8	-0.21	-0.32
^{134}Cs (GL)	19.00 ± 0.85	19.57 ± 0.28	-2.9	-0.64	-0.50
^{210}Pb (GL)	14.5 ± 1.8	15.00 ± 0.16	-3.3	-0.28	-0.57
^{241}Am (GL)	2.6 ± 0.3	2.5082 ± 0.0054	3.7	0.31	0.63


Deviation (%) of Laboratory 136
50
0
-50
^{3}H (B1)
^{14}C (B1)
^{58}Co (GL)
^{134}Cs (GL)
^{241}Am (GL)

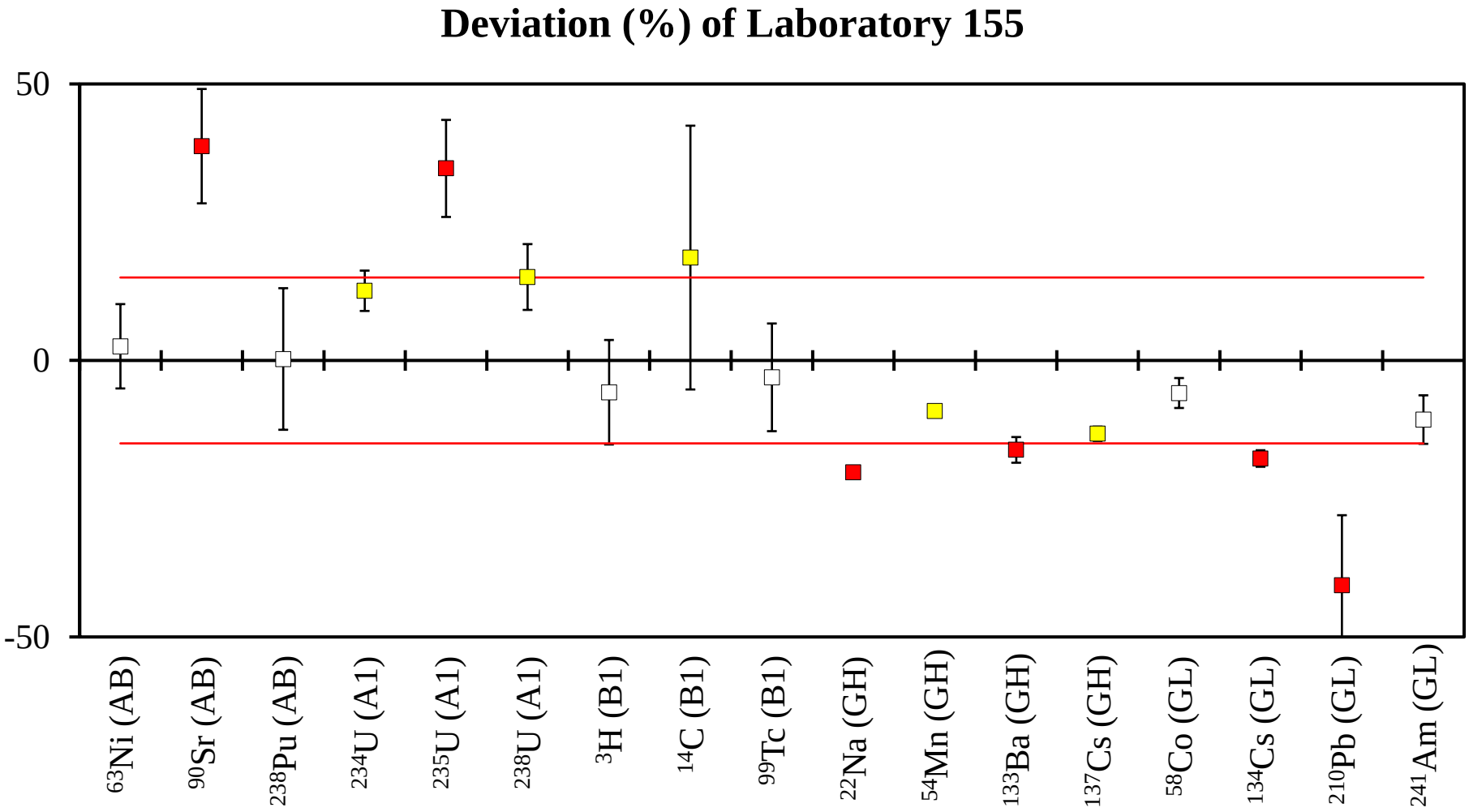
Radionuclide	Laboratory 136	NPL Assigned Value	Deviation (%)	Zeta	Z Score
^{3}H (B1)	0.537 ± 0.032	0.5655 ± 0.0071	-5.0	-0.87	-0.87
^{14}C (B1)	0.133 ± 0.011	0.1720 ± 0.0012	-22.7	-3.52	-3.89
^{58}Co (GL)	35.1 ± 1.8	34.64 ± 0.24	1.3	0.25	0.23
^{134}Cs (GL)	19.8 ± 1.6	19.57 ± 0.28	1.2	0.14	0.20
^{241}Am (GL)	2.39 ± 0.30	2.5082 ± 0.0054	-4.7	-0.39	-0.81


Deviation (%) of Laboratory 142
50
0
-50
58Co (GL)
134Cs (GL)
210Pb (GL)
241Am (GL)

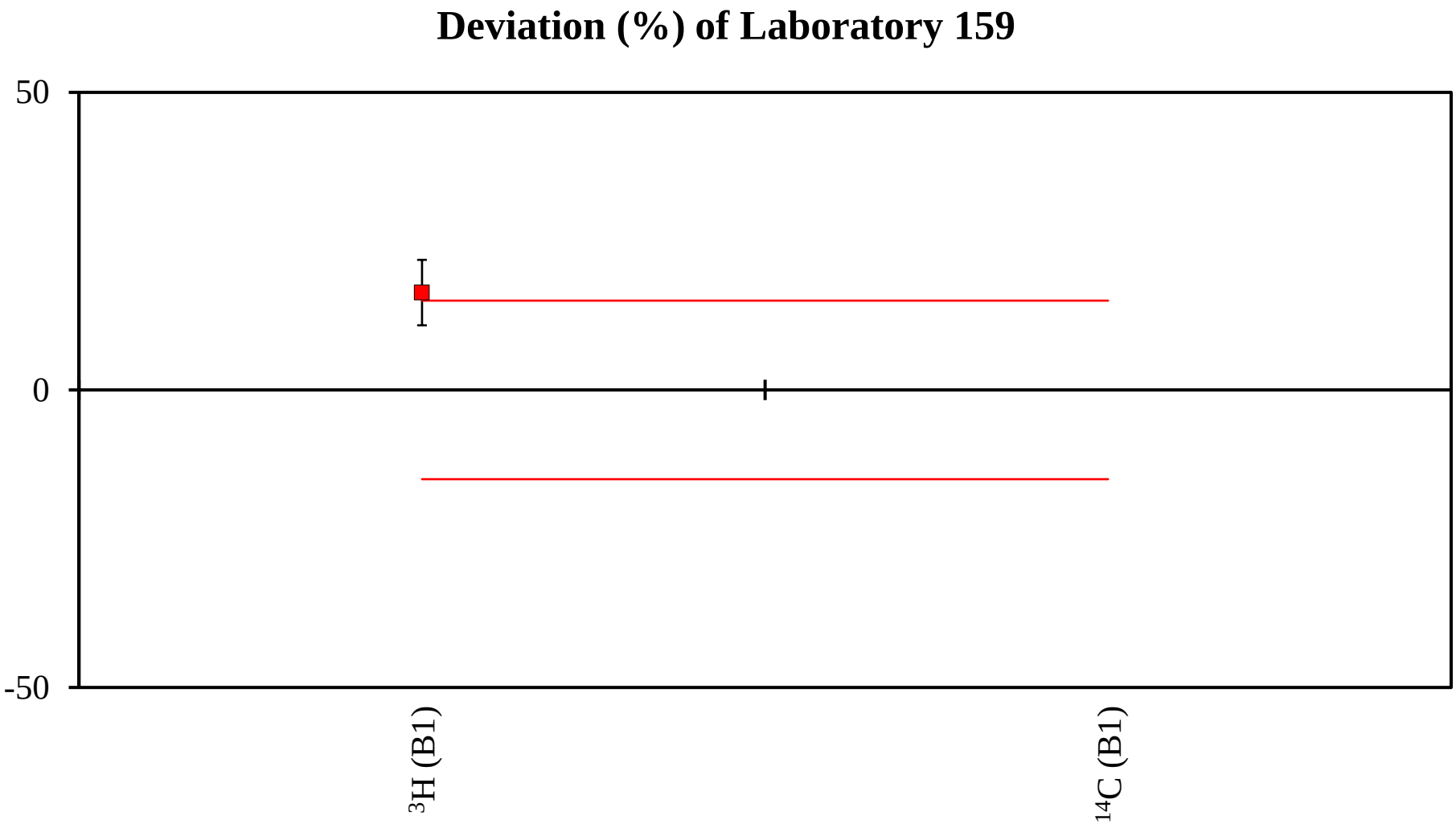
Radionuclide	Laboratory 142	NPL Assigned Value	Deviation (%)	Zeta	Z Score
^{58}Co (GL)	36.30 ± 0.47	34.64 ± 0.24	4.8	3.15	0.82
^{134}Cs (GL)	17.60 ± 0.10	19.57 ± 0.28	-10.1	-6.63	-1.73
^{210}Pb (GL)	9.3 ± 4.1	15.00 ± 0.16	-38.0	-1.39	-6.53
^{241}Am (GL)	2.43 ± 0.13	2.5082 ± 0.0054	-3.1	-0.60	-0.54


Deviation (%) of Laboratory 149
50
0
-50
^{22}Na (GH)
^{54}Mn (GH)
^{133}Ba (GH)
^{137}Cs (GH)
^{58}Co (GL)
^{134}Cs (GL)
^{210}Pb (GL)
^{241}Am (GL)

Radionuclide	Laboratory 149	NPL Assigned Value	Deviation (%)	Zeta	Z Score
^{22}Na (GH)	2.175 ± 0.017	16.672 ± 0.068	-87.0	-206.83	-14.93
^{54}Mn (GH)	11.910 ± 0.095	11.446 ± 0.043	4.1	4.45	0.70
^{133}Ba (GH)	13.69 ± 0.20	16.94 ± 0.12	-19.2	-13.93	-3.29
^{137}Cs (GH)	8.818 ± 0.062	8.612 ± 0.064	2.4	2.31	0.41
^{58}Co (GL)	42.57 ± 0.43	34.64 ± 0.24	22.9	16.10	3.93
^{134}Cs (GL)	20.66 ± 0.17	19.57 ± 0.28	5.6	3.33	0.96
^{210}Pb (GL)	16.22 ± 0.18	15.00 ± 0.16	8.1	5.07	1.40
^{241}Am (GL)	2.9002 ± 0.0087	2.5082 ± 0.0054	15.6	38.28	2.68


Deviation (%) of Laboratory 155
50
0
-50
63Ni (AB)
90Sr (AB)
238Pu (AB)
234U (A1)
235U (A1)
238U (A1)
3H (B1)
14C (B1)
99Tc (B1)
22Na (GH)
54Mn (GH)
133Ba (GH)
137Cs (GH)
58Co (GL)
134Cs (GL)
210Pb (GL)
241Am (GL)

Radionuclide	Laboratory 155	NPL Assigned Value	Deviation (%)	Zeta	Z Score
^{63}Ni (AB)	2.04 ± 0.15	1.989 ± 0.022	2.6	0.34	0.44
^{90}Sr (AB)	2.82 ± 0.21	2.0324 ± 0.0054	38.8	3.75	6.66
^{238}Pu (AB)	9.4 ± 1.2	9.375 ± 0.021	0.3	0.02	0.05
^{234}U (A1)	21.45 ± 0.64	19.05 ± 0.24	12.6	3.51	2.16
^{235}U (A1)	0.904 ± 0.057	0.671 ± 0.011	34.7	4.01	5.96
^{238}U (A1)	16.17 ± 0.81	14.05 ± 0.18	15.1	2.55	2.59
^{3}H (B1)	0.533 ± 0.053	0.5655 ± 0.0071	-5.7	-0.61	-0.99
^{14}C (B1)	0.204 ± 0.041	0.1720 ± 0.0012	18.6	0.78	3.20
^{99}Tc (B1)	0.200 ± 0.020	0.2063 ± 0.0019	-3.1	-0.31	-0.52
^{22}Na (GH)	13.30 ± 0.16	16.672 ± 0.068	-20.2	-19.40	-3.47
^{54}Mn (GH)	10.40 ± 0.11	11.446 ± 0.043	-9.1	-8.86	-1.57
^{133}Ba (GH)	14.20 ± 0.38	16.94 ± 0.12	-16.2	-6.88	-2.78
^{137}Cs (GH)	7.470 ± 0.096	8.612 ± 0.064	-13.3	-9.90	-2.28
^{58}Co (GL)	32.60 ± 0.91	34.64 ± 0.24	-5.9	-2.17	-1.01
^{134}Cs (GL)	16.10 ± 0.18	19.57 ± 0.28	-17.7	-10.42	-3.05
^{210}Pb (GL)	8.9 ± 1.9	15.00 ± 0.16	-40.7	-3.20	-6.98
^{241}Am (GL)	2.24 ± 0.11	2.5082 ± 0.0054	-10.7	-2.44	-1.84


Deviation (%) of Laboratory 159
50
0
-50
3H (B1)
14C (B1)

Radionuclide	Laboratory 159	NPL Assigned Value	Deviation (%)	Zeta	Z Score
^{3}H (B1)	0.658 ± 0.030	0.5655 ± 0.0071	16.4	3.00	2.81
^{14}C (B1)	0.335 ± 0.015	0.1720 ± 0.0012	94.8	10.83	16.27
Gross beta (B1)	0.276 ± 0.021	-	-	-	-

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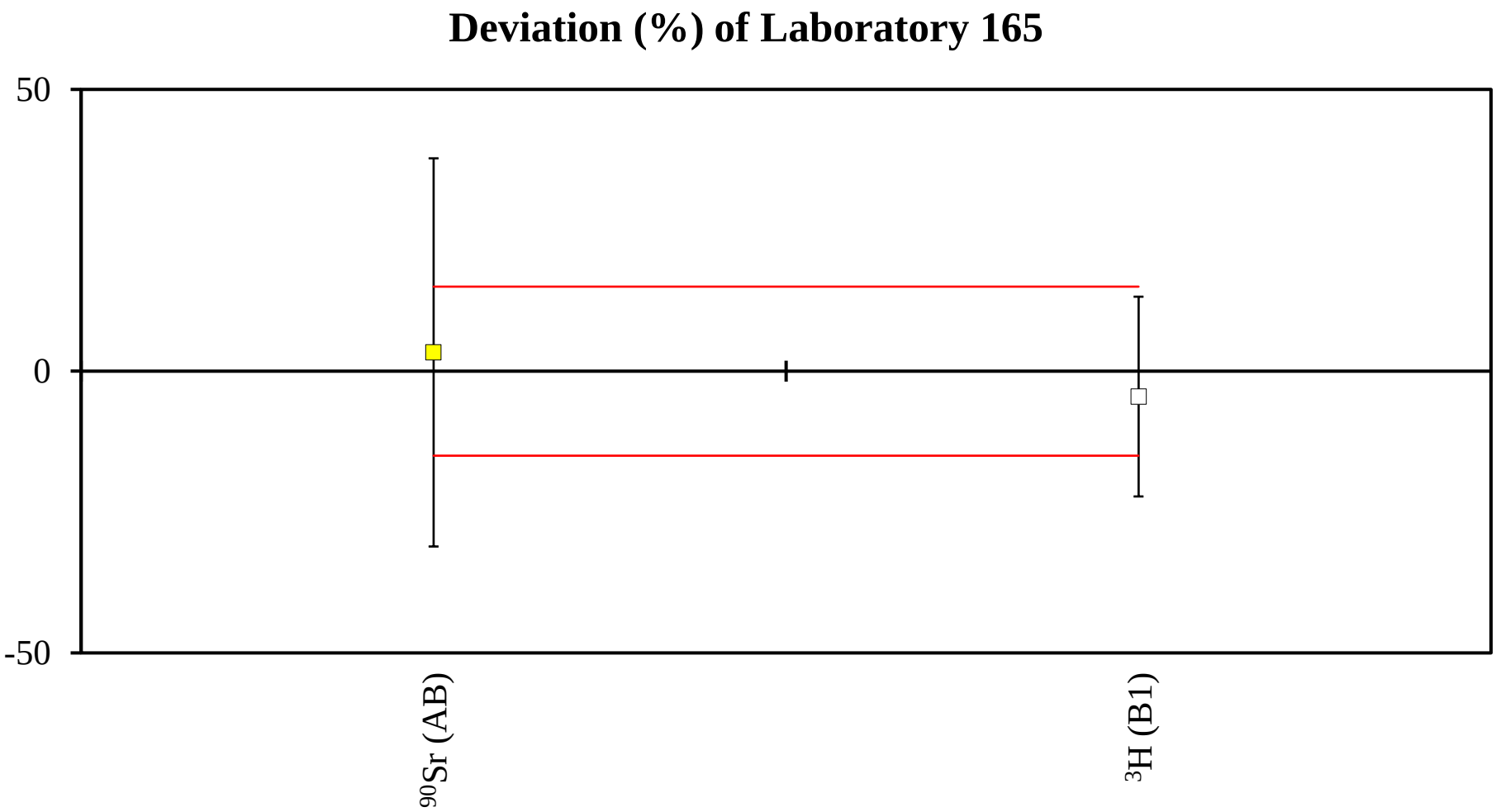
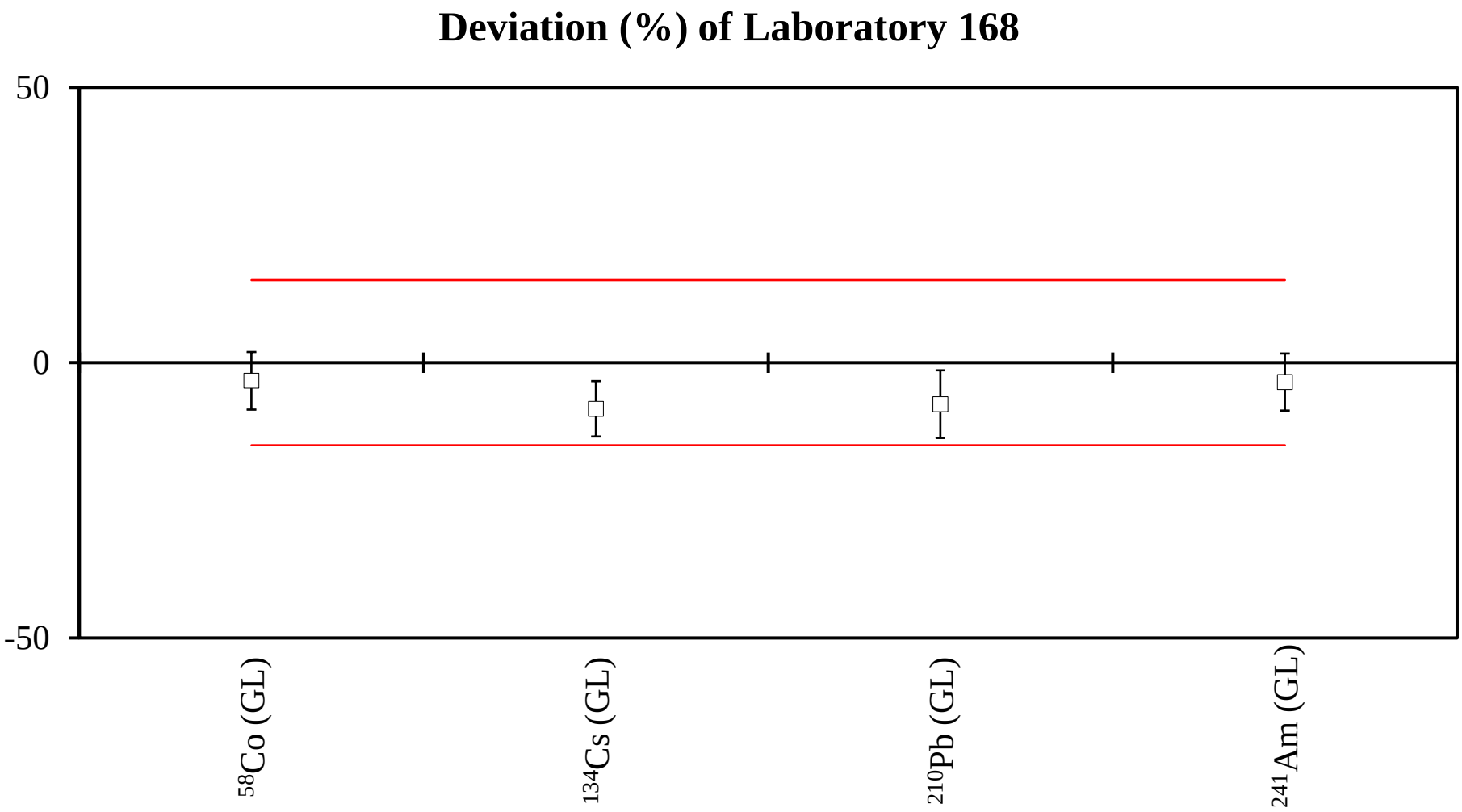
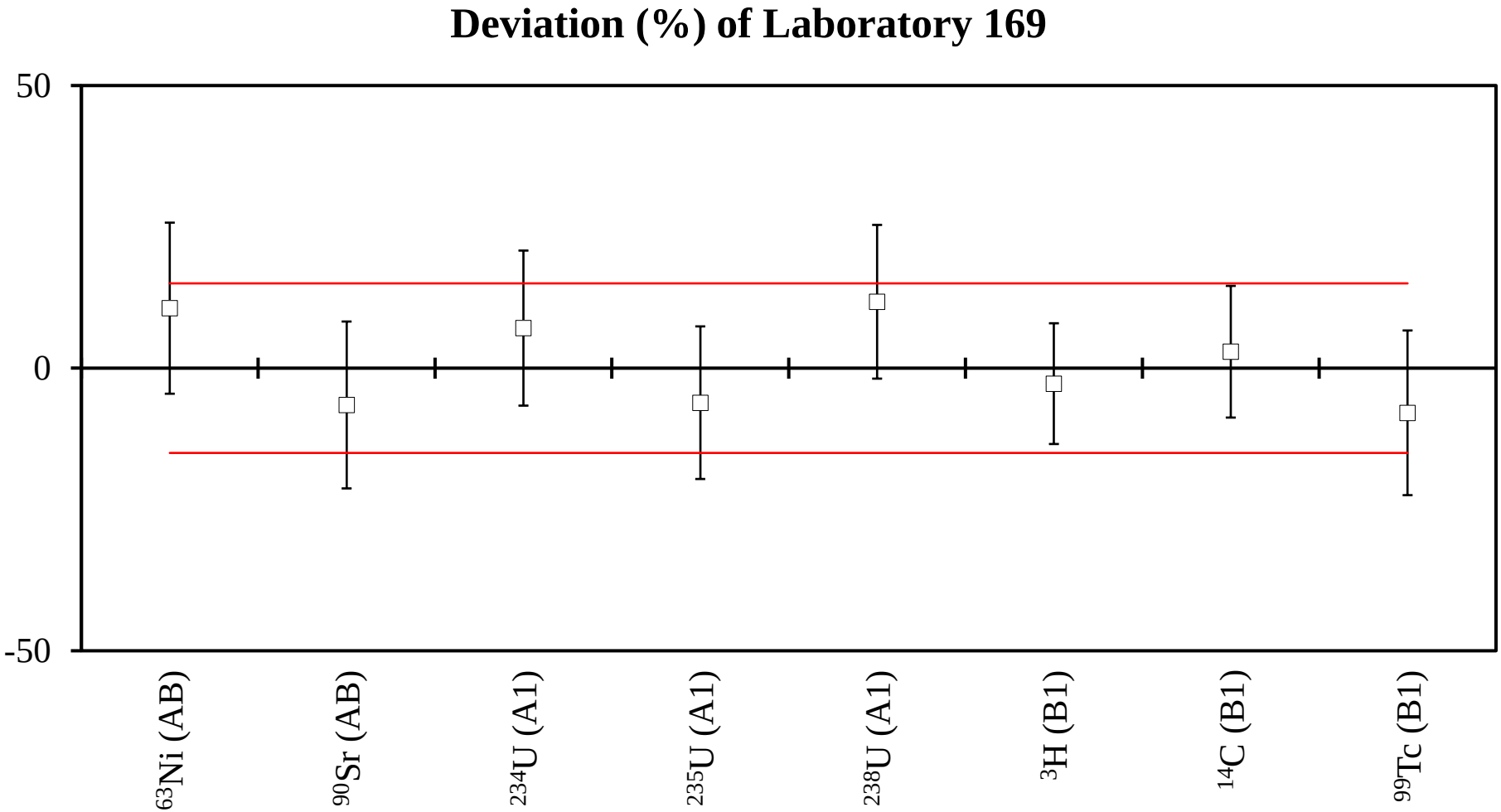

Deviation (%) of Laboratory 165
50
0
-50
^{90}Sr (AB)
^{3}H (B1)

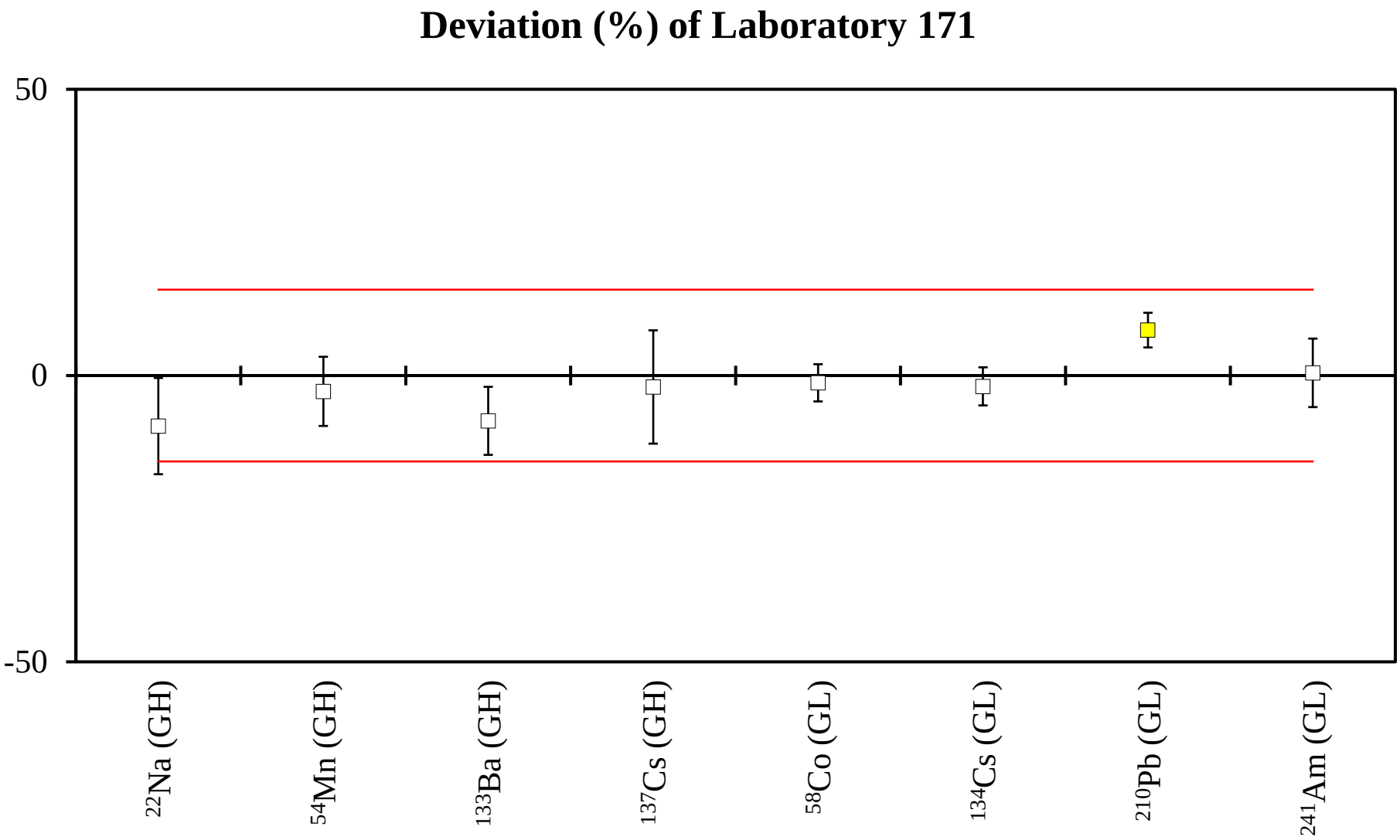
Radionuclide	Laboratory 165	NPL Assigned Value	Deviation (%)	Zeta	Z Score
^{90}Sr (AB)	2.1 ± 0.7	2.0324 ± 0.0054	3.3	0.10	0.57
^{3}H (B1)	0.54 ± 0.10	0.5655 ± 0.0071	-4.5	-0.25	-0.77


Deviation (%) of Laboratory 168
50
0
-50
58Co (GL)
134Cs (GL)
210Pb (GL)
241Am (GL)

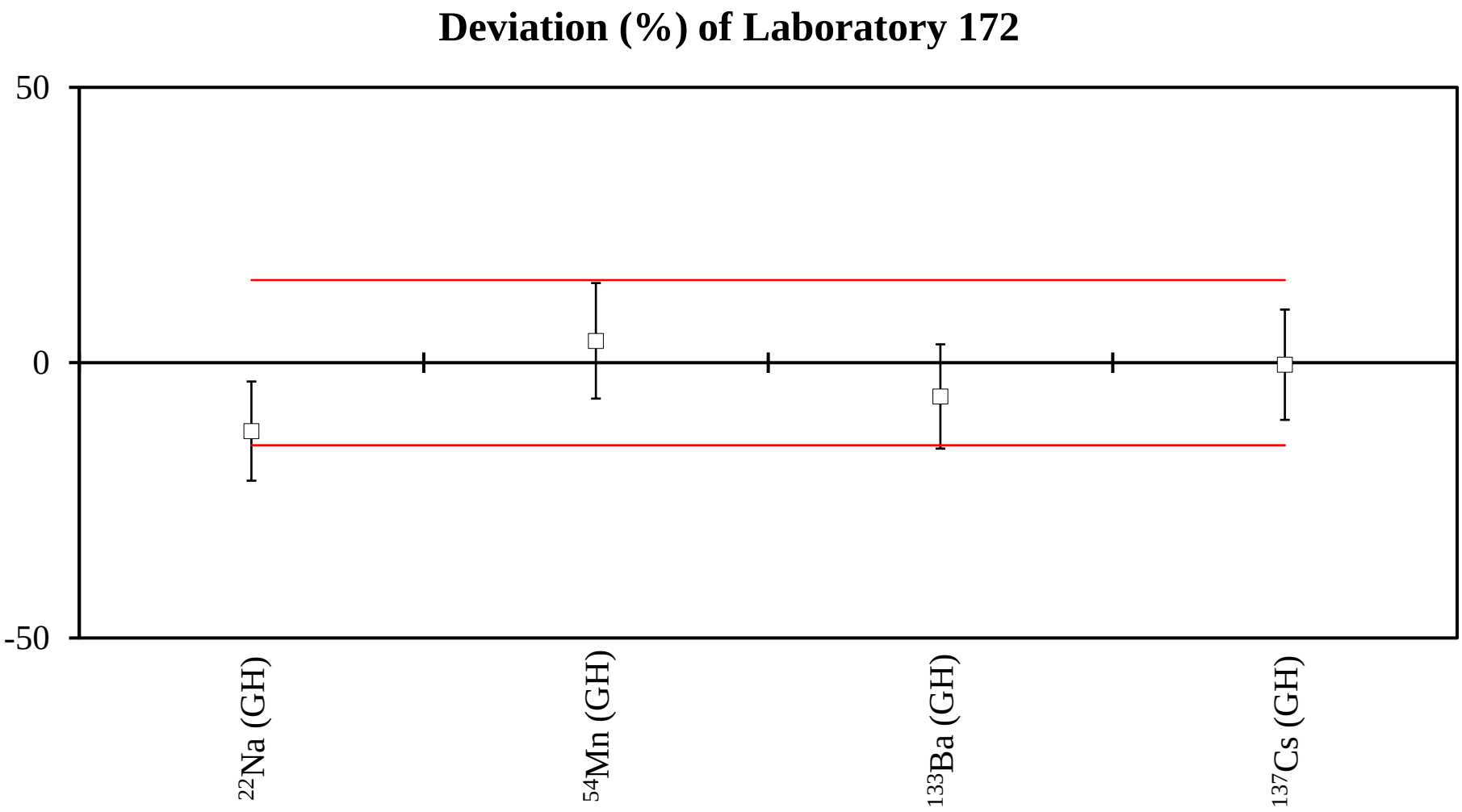
Radionuclide	Laboratory 168	NPL Assigned Value	Deviation (%)	Zeta	Z Score
^{58}Co (GL)	33.5 ± 1.8	34.64 ± 0.24	-3.3	-0.63	-0.57
^{134}Cs (GL)	17.93 ± 0.95	19.57 ± 0.28	-8.4	-1.66	-1.44
^{210}Pb (GL)	13.87 ± 0.91	15.00 ± 0.16	-7.5	-1.22	-1.29
^{241}Am (GL)	2.42 ± 0.13	2.5082 ± 0.0054	-3.5	-0.68	-0.60


Deviation (%) of Laboratory 169
50
0
-50
63Ni (AB)
90Sr (AB)
234U (A1)
235U (A1)
238U (A1)
3H (B1)
14C (B1)
99Tc (B1)

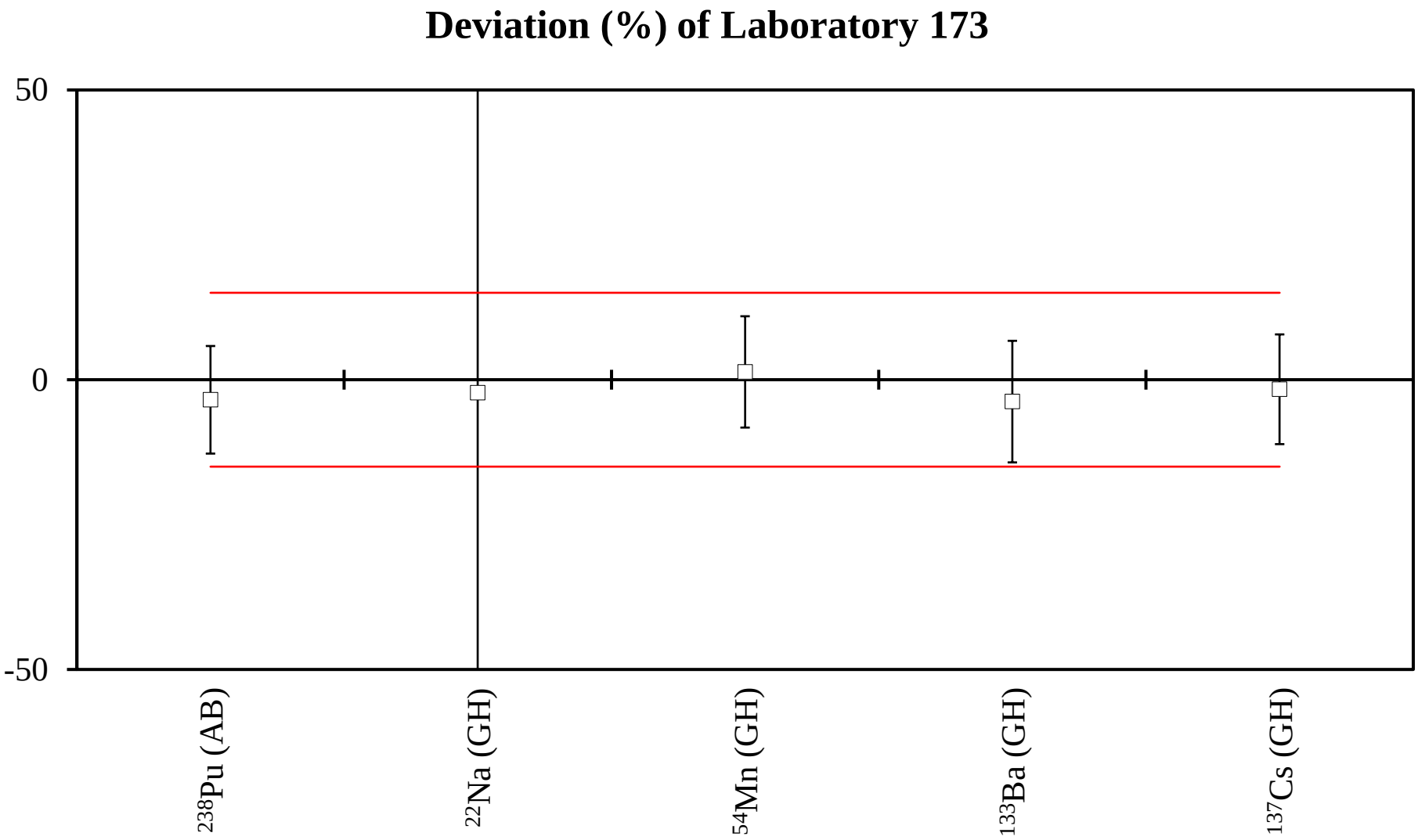
Radionuclide	Laboratory 169	NPL Assigned Value	Deviation (%)	Zeta	Z Score
^{63}Ni (AB)	2.2 ± 0.3	1.989 ± 0.022	10.6	0.70	1.82
^{90}Sr (AB)	1.9 ± 0.3	2.0324 ± 0.0054	-6.5	-0.44	-1.12
^{234}U (A1)	20.4 ± 2.6	19.05 ± 0.24	7.1	0.52	1.22
^{235}U (A1)	0.63 ± 0.09	0.671 ± 0.011	-6.1	-0.45	-1.05
^{238}U (A1)	15.7 ± 1.9	14.05 ± 0.18	11.7	0.86	2.02
^{3}H (B1)	0.55 ± 0.06	0.5655 ± 0.0071	-2.7	-0.26	-0.47
^{14}C (B1)	0.177 ± 0.020	0.1720 ± 0.0012	2.9	0.25	0.50
^{99}Tc (B1)	0.19 ± 0.03	0.2063 ± 0.0019	-7.9	-0.54	-1.36


Deviation (%) of Laboratory 171
50
0
-50
22Na (GH)
54Mn (GH)
133Ba (GH)
137Cs (GH)
58Co (GL)
134Cs (GL)
210Pb (GL)
241Am (GL)

Radionuclide	Laboratory 171	NPL Assigned Value	Deviation (%)	Zeta	Z Score
^{22}Na (GH)	15.2 ± 1.4	16.672 ± 0.068	-8.8	-1.05	-1.52
^{54}Mn (GH)	11.13 ± 0.69	11.446 ± 0.043	-2.8	-0.46	-0.47
^{133}Ba (GH)	15.6 ± 1.0	16.94 ± 0.12	-7.9	-1.33	-1.36
^{137}Cs (GH)	8.44 ± 0.85	8.612 ± 0.064	-2.0	-0.20	-0.34
^{58}Co (GL)	34.2 ± 1.1	34.64 ± 0.24	-1.3	-0.39	-0.22
^{134}Cs (GL)	19.20 ± 0.59	19.57 ± 0.28	-1.9	-0.57	-0.32
^{210}Pb (GL)	16.19 ± 0.42	15.00 ± 0.16	7.9	2.65	1.36
^{241}Am (GL)	2.52 ± 0.15	2.5082 ± 0.0054	0.5	0.08	0.08

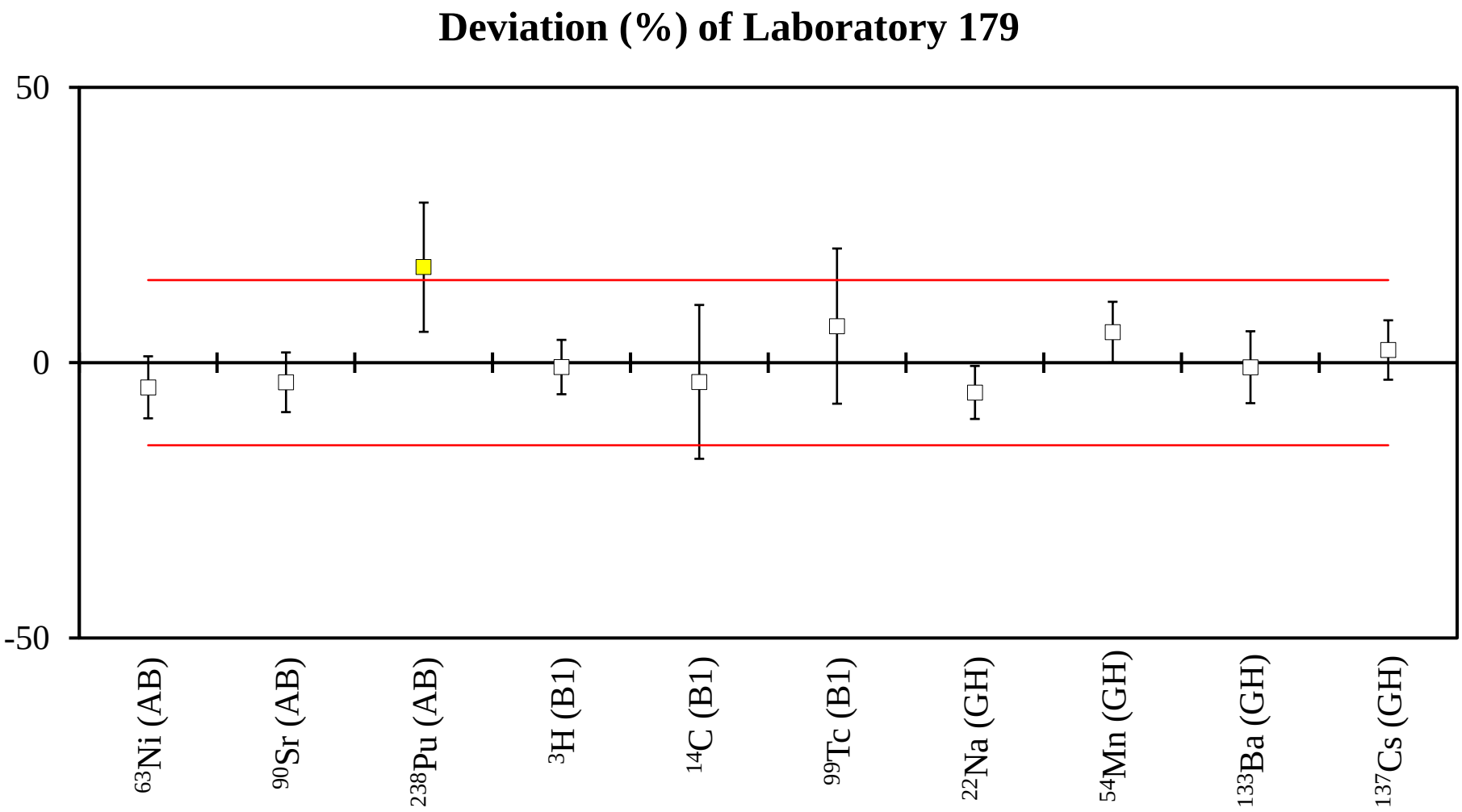

Deviation (%) of Laboratory 172
50
0
-50
22Na (GH)
54Mn (GH)
133Ba (GH)
137Cs (GH)

Radionuclide	Laboratory 172	NPL Assigned Value	Deviation (%)	Zeta	Z Score
^{22}Na (GH)	14.6 ± 1.5	16.672 ± 0.068	-12.4	-1.38	-2.13
^{54}Mn (GH)	11.9 ± 1.2	11.446 ± 0.043	4.0	0.38	0.68
^{133}Ba (GH)	15.9 ± 1.6	16.94 ± 0.12	-6.1	-0.65	-1.05
^{137}Cs (GH)	8.58 ± 0.86	8.612 ± 0.064	-0.4	-0.04	-0.06

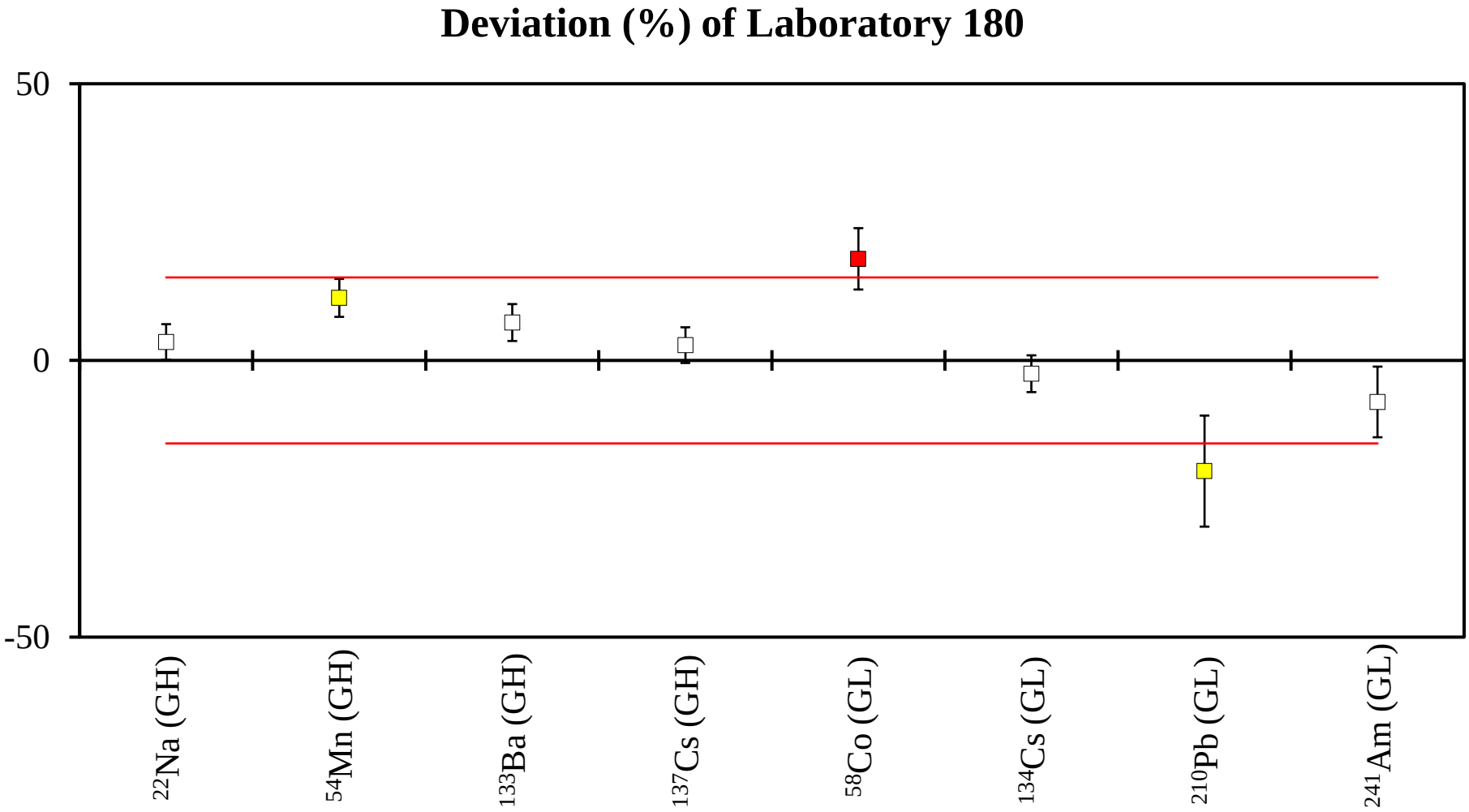

Deviation (%) of Laboratory 173
50
0
-50
238Pu (AB)
22Na (GH)
54Mn (GH)
133Ba (GH)
137Cs (GH)

Radionuclide	Laboratory 173	NPL Assigned Value	Deviation (%)	Zeta	Z Score
^{238}Pu (AB)	9.05 ± 0.87	9.375 ± 0.021	-3.5	-0.37	-0.60
Gross beta (AB)	32.8 ± 3.2	-	-	-	-
^{22}Na (GH)	16.3 ± 1.6	16.672 ± 0.068	-2.2	-0.23	-0.38
^{54}Mn (GH)	11.6 ± 1.2	11.446 ± 0.043	1.3	0.13	0.23
^{133}Ba (GH)	16.3 ± 1.6	16.94 ± 0.12	-3.8	-0.40	-0.65
^{137}Cs (GH)[4]	8.47 ± 0.85	8.612 ± 0.064	-1.6	-0.17	-0.28

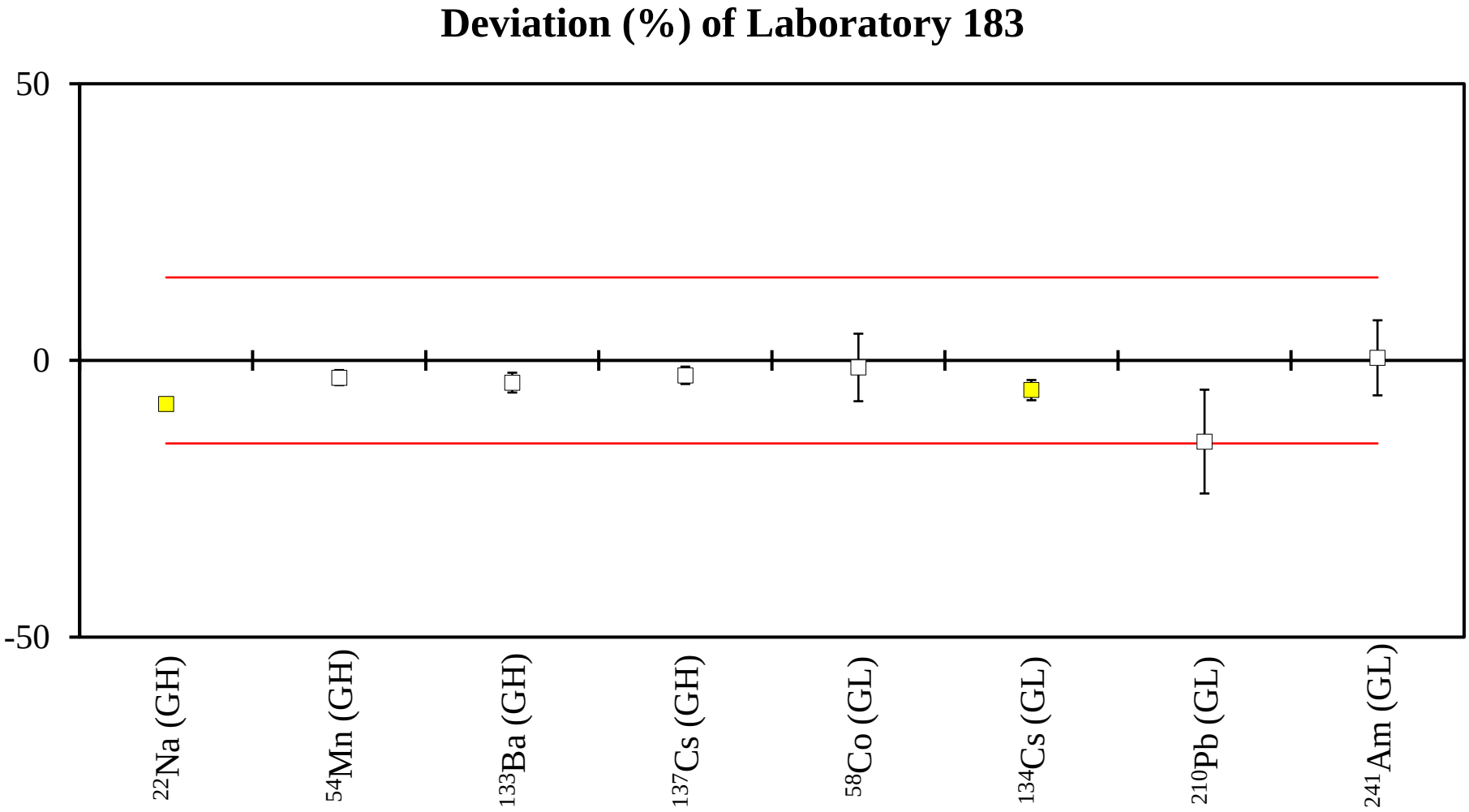
[4] Please note that the in the original reporting form the results for ^{133}Ba and ^{137}Cs were reversed. This transcription error has been amended in the final report.


Deviation (%) of Laboratory 179
50
0
-50
63Ni (AB)
90Sr (AB)
238Pu (AB)
3H (B1)
14C (B1)
99Tc (B1)
22Na (GH)
54Mn (GH)
133Ba (GH)
137Cs (GH)

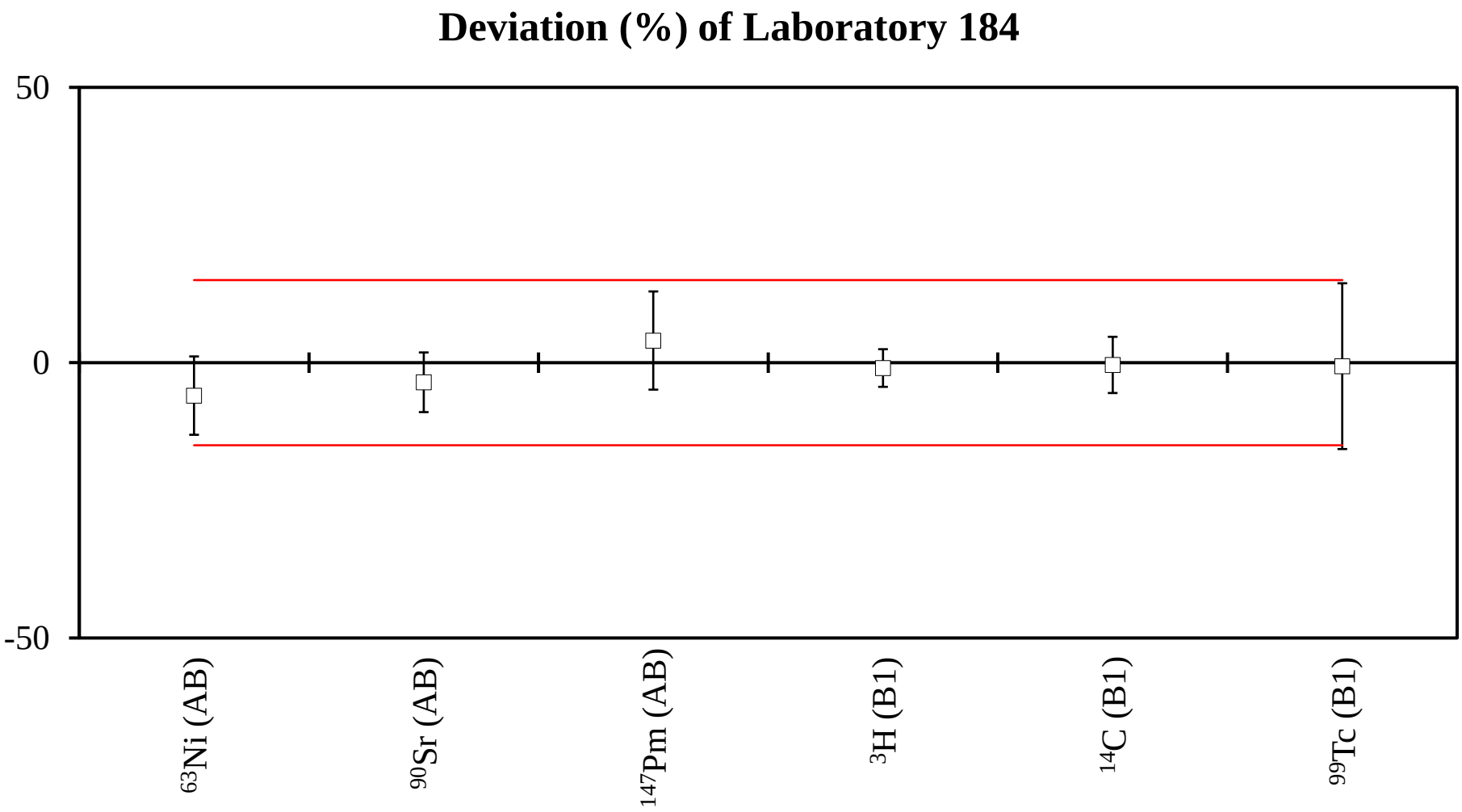
Radionuclide	Laboratory 179	NPL Assigned Value	Deviation (%)	Zeta	Z Score
^{63}Ni (AB)	1.90 ± 0.11	1.989 ± 0.022	-4.5	-0.79	-0.77
^{90}Sr (AB)	1.96 ± 0.11	2.0324 ± 0.0054	-3.6	-0.66	-0.61
^{238}Pu (AB)	11.0 ± 1.1	9.375 ± 0.021	17.3	1.48	2.98
^{3}H (B1)	0.561 ± 0.027	0.5655 ± 0.0071	-0.8	-0.16	-0.14
^{14}C (B1)	0.166 ± 0.024	0.1720 ± 0.0012	-3.5	-0.25	-0.60
^{99}Tc (B1)	0.220 ± 0.029	0.2063 ± 0.0019	6.6	0.47	1.14
^{22}Na (GH)	15.77 ± 0.80	16.672 ± 0.068	-5.4	-1.12	-0.93
^{54}Mn (GH)	12.08 ± 0.63	11.446 ± 0.043	5.5	1.00	0.95
^{133}Ba (GH)	16.8 ± 1.1	16.94 ± 0.12	-0.8	-0.13	-0.14
^{137}Cs (GH)	8.81 ± 0.46	8.612 ± 0.064	2.3	0.43	0.39


Deviation (%) of Laboratory 180
50
0
-50
22Na (GH)
54Mn (GH)
133Ba (GH)
137Cs (GH)
58Co (GL)
134Cs (GL)
210Pb (GL)
241Am (GL)

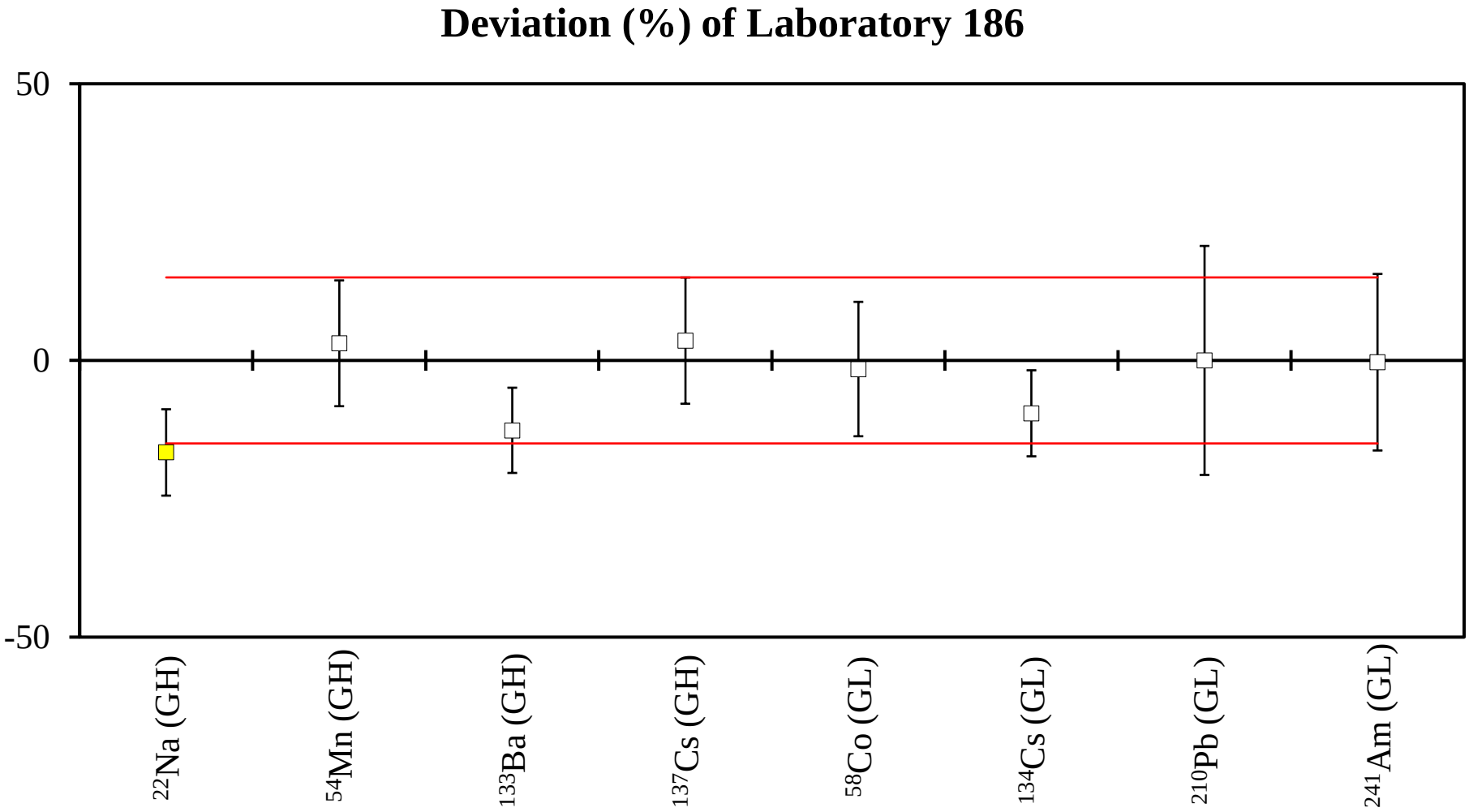
Radionuclide	Laboratory 180	NPL Assigned Value	Deviation (%)	Zeta	Z Score
^{22}Na (GH)	17.23 ± 0.53	16.672 ± 0.068	3.3	1.04	0.57
^{54}Mn (GH)	12.74 ± 0.39	11.446 ± 0.043	11.3	3.30	1.94
^{133}Ba (GH)	18.10 ± 0.55	16.94 ± 0.12	6.8	2.06	1.18
^{137}Cs (GH)	8.85 ± 0.27	8.612 ± 0.064	2.8	0.86	0.47
^{58}Co (GL)	41.0 ± 1.9	34.64 ± 0.24	18.4	3.32	3.15
^{134}Cs (GL)	19.10 ± 0.59	19.57 ± 0.28	-2.4	-0.72	-0.41
^{210}Pb (GL)	12.0 ± 1.5	15.00 ± 0.16	-20.0	-1.99	-3.43
^{241}Am (GL)	2.32 ± 0.16	2.5082 ± 0.0054	-7.5	-1.18	-1.29


Deviation (%) of Laboratory 183
50
0
-50
22Na (GH)
54Mn (GH)
133Ba (GH)
137Cs (GH)
58Co (GL)
134Cs (GL)
210Pb (GL)
241Am (GL)

Radionuclide	Laboratory 183	NPL Assigned Value	Deviation (%)	Zeta	Z Score
^{22}Na (GH)	15.36 ± 0.14	16.672 ± 0.068	-7.9	-8.43	-1.35
^{54}Mn (GH)	11.09 ± 0.15	11.446 ± 0.043	-3.1	-2.28	-0.53
^{133}Ba (GH)	16.26 ± 0.28	16.94 ± 0.12	-4.0	-2.23	-0.69
^{137}Cs (GH)	8.38 ± 0.12	8.612 ± 0.064	-2.7	-1.71	-0.46
^{58}Co (GL)	34.2 ± 2.1	34.64 ± 0.24	-1.3	-0.21	-0.22
^{134}Cs (GL)	18.52 ± 0.24	19.57 ± 0.28	-5.4	-2.85	-0.92
^{210}Pb (GL)	12.8 ± 1.4	15.00 ± 0.16	-14.7	-1.56	-2.52
^{241}Am (GL)	2.52 ± 0.17	2.5082 ± 0.0054	0.5	0.07	0.08


Deviation (%) of Laboratory 184
50
0
-50
^{63}Ni (AB)
^{90}Sr (AB)
^{147}Pm (AB)
^{3}H (B1)
^{14}C (B1)
^{99}Tc (B1)

Radionuclide	Laboratory 184	NPL Assigned Value	Deviation (%)	Zeta	Z Score
^{63}Ni (AB)	1.87 ± 0.14	1.989 ± 0.022	-6.0	-0.84	-1.03
^{90}Sr (AB)	1.96 ± 0.11	2.0324 ± 0.0054	-3.6	-0.66	-0.61
^{147}Pm (AB)	17.6 ± 1.5	16.92 ± 0.16	4.0	0.45	0.69
^{3}H (B1)	0.560 ± 0.018	0.5655 ± 0.0071	-1.0	-0.28	-0.17
^{14}C (B1)	0.1713 ± 0.0087	0.1720 ± 0.0012	-0.4	-0.08	-0.07
^{99}Tc (B1)	0.205 ± 0.031	0.2063 ± 0.0019	-0.6	-0.04	-0.11


Deviation (%) of Laboratory 186
50
0
-50
22Na (GH)
54Mn (GH)
133Ba (GH)
137Cs (GH)
58Co (GL)
134Cs (GL)
210Pb (GL)
241Am (GL)

Radionuclide	Laboratory 186	NPL Assigned Value	Deviation (%)	Zeta	Z Score
^{22}Na (GH)	13.9 ± 1.3	16.672 ± 0.068	-16.6	-2.13	-2.86
^{54}Mn (GH)	11.8 ± 1.3	11.446 ± 0.043	3.1	0.27	0.53
^{133}Ba (GH)	14.8 ± 1.3	16.94 ± 0.12	-12.6	-1.64	-2.17
^{137}Cs (GH)	8.92 ± 0.98	8.612 ± 0.064	3.6	0.31	0.61
^{58}Co (GL)	34.1 ± 4.2	34.64 ± 0.24	-1.6	-0.13	-0.27
^{134}Cs (GL)	17.7 ± 1.5	19.57 ± 0.28	-9.6	-1.23	-1.64
^{210}Pb (GL)	15.0 ± 3.1	15.00 ± 0.16	0.0	0.00	0.00
^{241}Am (GL)	2.50 ± 0.40	2.5082 ± 0.0054	-0.3	-0.02	-0.06

11. DISCUSSION

Please note that, due to poor consistency in the datasets and magnitude of the uncertainties for the PMM of the gross beta measurement results, a decision by the PTE committee was taken to not to declare Assigned Values for performance evaluations as there was not sufficient confidence in the accuracy of these values (Table 7). It should also be noted that in some cases participants did not report methods and/or techniques used. The information provided below therefore refers to subset of participants (for each radionuclide) who did report such information. In order for NPL to provide performance related feedback, it is encouraged that participants detail the methods and techniques used.

11.1 Nickel-63 in AB

In total 15 results were provided for ^{63}Ni in the AB sample type, with 12 in agreement, one questionable and two discrepant. The uptake in measurement of ^{63}Ni was similar to the last time ^{63}Ni was included in the AB sample type and 16 results were provided (2017). When compared to the 2017 results the proportion of results in agreement with the NPL value increased from 56 % to 80 % and the overall deviation reduced from − 10.3 % to 1.0 %. The questionable result for ^{63}Ni is due to failure of the R_L test, there were no details provided regarding the methods and techniques used. If the methods and techniques differed significantly from that of other participants, it may be that the uncertainty is correct.

Of the reporting laboratories 12 of the 15 provided a techniques form including various levels of detail relating to the methodologies used. Radiochemistry involved included solvent extraction (with DMG, dimethyl glyoxime), DMG-based extraction chromatography (Ni-resin, TrisKem International), and ion exchange. Anion exchange was also performed following precipitation of Ni as a hydroxide. As with the 2017 exercise, all laboratories reported using Liquid Scintillation Counting (LSC) as the detection technique. In some instances, chemical yield was determined using ICP-MS measurement of stable Ni (4) with other laboratories opting for the use of parallel standards of ^{63}Ni (4).

11.2 Strontium-90 in AB

For the ^{90}Sr in the AB sample type 26 results were submitted of which 22 were in agreement, two were questionable and two were discrepant. One of the questionable results was due to its large relative uncertainty which may be due to differences in the uncertainty budget for low-level alpha beta counting.

Of the reporting laboratories 22 of the 26 provided techniques form. This detailed the pre-treatment and separation techniques used. The most common separation technique was extraction chromatography (10), many of whom stated using Sr resin from either TrisKem International or Eichrom Technologies. One laboratory reported using liquid extraction with bis(2-ethylhexyl)phosphoric acid (HDEHP) following sulphate precipitation and carbonation steps. The yield for this method was traced using stable Sr (^{88}Sr), measured by ICP-MS, and provided results in good agreement with the assigned value. This sort of methodology would be of particular interest to laboratories doing low level analysis of large volume samples.

Laboratories reported using Cherenkov counting (5), low-level alpha beta counting (1), LSC (11) proportional counting (4), as the detection technique. In some instances (5), like the method described above, the chemical yield was determined using ICP-MS measurement of stable Sr (^{88}Sr) with other laboratories opting to add ^{85}Sr (5) as an internal tracer. Parallel standards containing ^{90}Sr were also used (6).

The PMM of Cherenkov counting and LSC results were as follows:

Cherenkov Counting: (2.11 ± 0.19) Bq g^{-1}
Liquid Scintillation Counting: (2.005 ± 0.045) Bq g^{-1}

These results suggest there is no significant difference between results obtained using each method. Due to the size of the dataset and the varied methods leading up to the final analysis it is difficult to confirm. No notable differences between measurement methods have been observed from ^{90}Sr in recent exercises which provides more confidence in that observation. The lower standard uncertainty on the PMM result for LSC does not indicate a more precise technique but a more consistent dataset ($\chi^2/\nu = 0.81$). The Cherenkov counting technique dataset had a $\chi^2/\nu = 2.1$. The median relative uncertainties were 8% and 6% for Cherenkov counting and LSC respectively.

11.3 Promethium-147 in AB

As with the 2018 exercise, six results were reported for this radionuclide, with four of the six reporting laboratories providing a techniques form. Of the results submitted three were in agreement with the assigned value with an overall bias of − 7.3% which is an improvement from the previous exercises, − 21.4%. Radiochemistry involved included ion exchange (2) and extraction chromatography (1). Laboratories reported using liquid scintillation counting (4). Tracers and yields monitors included ^{147}Pm (2) and Sm (1).

11.4 Plutonium-238 in AB

This year's exercise saw 21 results submitted for ^{238}Pu. Of these results, 18 were in agreement with the assigned value and three were questionable with an overall bias of − 2.4% which is larger in magnitude than that of the 2017 exercise (0.4%), although the difference is not statistically significant.

Of the 21 reporting laboratories, 16 provided a techniques form. Radiochemistry was diverse with multiple methodologies described, including: anion (3) and cation (4) exchange preceded by varied oxidation and precipitation steps, and extraction chromatography (4) with TRU resin (TrisKem International) was also described. The only recorded source preparation technique was electrodeposition (5). The dominant tracer for recovery and counting efficiency was ^{242}Pu with one laboratory opting for ^{236}Pu. The result reporting using ^{236}Pu provided a result in agreement with the NPL reference value.

The dominant detection technique for ^{238}Pu was alpha spectrometry (14) with the other laboratory opting for alpha scintillation with a ZnS photon multiplier tube. Alpha scintillation result accounted for one of the questionable results.

11.5 Uranium-234 in A1

This year's exercise provided a sample containing ^{234}U, ^{235}U and ^{238}U in which the ^{234}U was not present at its natural ratio. A total of 20 results were submitted for ^{234}U with 16 in agreement with the assigned value.

Radiochemical separation methods used prior to measurement included cation (6) and anion (3) exchange as well as extraction chromatography (5) with some laboratories opting for an exchange-based clean-up followed by extraction chromatography (3). One laboratory stated using UTEVA following a clean-up on anion exchange resin. One laboratory opted for dilution followed by multi-collector inductively coupled mass spectrometry (MC-ICP-MS) which provided a result in good agreement with the assigned value.

Detection of ^{234}U was carried out by alpha spectrometry (12) and mass spectrometry (3) with ^{232}U predominantly used as a tracer. The PMM of alpha spectrometry and mass spectrometry results were as follows:

Alpha Spectrometry: (18.75 ± 0.15) Bq kg^{-1}
Mass Spectrometry: (18.82 ± 0.68) Bq kg^{-1}

The PMM was derived from 10 of the 12 results submitted for alpha spectrometry and all three of the mass spectrometry results. These results suggest there is no significant difference between the two detection techniques, but the comments for the ^{90}Sr method comparisons also apply here. The difference in standard uncertainty between the two measurement techniques is not linked to the level of precision of the measurement techniques but rather the number of results submitted; more results were submitted for alpha spectrometry (12), resulting in a more precise standard uncertainty. The median of the relative standard uncertainty of both techniques was 6%. For measurement of U isotopes by ICP-MS, there are very few spectral interferences. Formation of $^{234}U^{1}H$ can contribute to ^{235}U, which can cause low mass tailing on ^{234}U but these contributions are not expected over the activity concentrations given for these isotopes.

11.6 Uranium-235 in A1

A total of 21 results were provided for ^{235}U with 17 in agreement with the assigned value, three being questionable and only discrepant result.

As expected, a similar array of preconcentration, separation and source preparation steps to ^{234}U were used. This was the same with regards to detection which was carried out using a mix of alpha spectrometry and mass spectrometry, with one laboratory choosing to use gamma spectrometry as a part of a secondary method.

The PMM of alpha spectrometry and mass spectrometry results were as follows:

Alpha Spectrometry: (0.6498 ± 0.0041) Bq kg^{-1}
Mass Spectrometry: (0.656 ± 0.023) Bq kg^{-1}

As with the ^{234}U comparison of techniques the lower standard uncertainty for alpha spectrometry is due the number of results submitted for each technique. The PMM was derived from 11 of the 12 results submitted for alpha spectrometry, and all three of the mass spectrometry results. The median relative uncertainty was higher for alpha spectrometry, at 11%, compared to that of mass spectrometry, at 7%

11.7 Uranium-238 in A1

For ^{238}U 21 results were submitted and of these 15 were in agreement with the assigned value, four were questionable and two were discrepant.

The radiochemistry techniques adopted by participating laboratories were the same as for the other U isotopes in the A1 mixed radionuclide sample. Detection was achieved using alpha spectrometry (13), mass spectrometry (2) and gamma spectrometry (1). The laboratory using gamma spectrometry measured ^{238}U by assuming secular equilibrium between ^{238}U and ^{234}Th via its 63 keV emission. This resulted in a value lower than the NPL which is likely due to disequilibria between ^{238}U and ^{234}Th. Another laboratory result detailed a method which measured ^{238}U by alpha spectrometry which then had correction factors applied from a secondary measurement by mass spectrometry.

The PMM of alpha spectrometry and mass spectrometry results were as follows:

Alpha Spectrometry: (13.958 ± 0.075) Bq kg^{-1}
Mass Spectrometry: (14.21 ± 0.45) Bq kg^{-1}

As with the PMM comparison for ^{234}U and ^{235}U, the lower standard uncertainty for the PMM of the alpha spectrometry results reflects the number of measurements which were submitted. The PMM was derived from 10 of the 12 results submitted for alpha spectrometry, and all three of the mass spectrometry results. The median relative uncertainty for alpha spectrometry was 5% and 7% for mass spectrometry.

11.8 Tritium in B1

This year's B1 sample included ^{3}H for which 32 measurement results were submitted. Of these results, 30 were in agreement with the assigned value and two were discrepant. One of the discrepant results may be attributed to a transcription error during reporting whilst the other cannot be commented on as no techniques form was submitted.

A number of chemistry techniques were used to prepare samples for measurement including, distillation (12), pyrolysis (4), combustion (1) and extraction chromatography (1). Pyrolysis was carried out in an oxygen rich atmosphere and the extraction chromatography-based method provided a result in good agreement with assigned value. There was one erroneous result with a deviation > 9000%, it may be assumed that this is due to a reporting error related to use of incorrect units.

All participating laboratories used LSC as the detection technique including both Quantulus (Perkin Elmer) and TriCarb (Perkin Elmer) instrument types with a standard source of ^{3}H.

11.9 Carbon-14 in B1

As with previous year ^{14}C was included in the B1 sample. A total of 21 results were provided with 14 in agreement, four questionable and three discrepant from the assigned value. One of the discrepant results may be attributed to incorrect units, though incorrect units would not account for the full deviation. The other low discrepant result reported using coprecipitation with Ba, as $Ba(CO_3)_2$, followed by direct measurement in InstaGel. This may be due to an over estimation of the counting efficiency or losses of ^{14}C from solution but there was no detail on whether parallel standards or reference sources were used. Another laboratory reported using a similar method, using both Ba precipitation followed by direct measurement in InstaGel, with results in good agreement with the assigned value.

One laboratory reported directly measuring the sample and provided results in good agreement with the assigned value. A number of other laboratories reporting using pyrolysis (5) as part of a combined method for ^{3}H and ^{14}C. All measurements were made by LSC.

11.10 Technetium-99 in B1

A total of 16 results were reported for ^{99}Tc with three discrepant results, all of which were lower than the assigned value. Of the discrepant results two laboratories reporting using LSC and one laboratory chose not to disclose the method used.

For mass spectrometry (ICP-MS) interferences include ^{98}Mo tailing, formation of polyatomic $^{98}Mo^{1}H$ and isobaric ^{99}Ru which can be monitored and potentially corrected for by monitoring ^{101}Ru. The B1 sample is prepared in 0.01 M NaOH. Some participating laboratories opted for direct measurement of ^{99}Tc or measurement after dilution with others opting for measurement post-separation. It is important that standards are matrix-matched as signal

response may differ between reagents. The use of a Re tracer is common for ^{99}Tc analysis, but the chemical behaviour of Re is different from Tc, with shorter-lived ^{99m}Tc often favoured and yield calculated using gamma spectrometry. This is particularly important for laboratories opting for extraction chromatography, which is highly selective and differences in retention factors could introduce errors into recovery calculations.

Both LSC (7) and mass spectrometry (6) were used. The PMM values of results for each detection technique were as follows:

Liquid Scintillation Counting: (0.1930 ± 0.0085) Bq g^{-1}
Mass Spectrometry: (0.1973 ± 0.0091) Bq g^{-1}

The PMM for LSC was derived from 5 of the 7 results submitted. Whilst, the standard uncertainty for the PMM of each technique was similar, the median relative uncertainties were 8% and 13% for LSC and MS respectively. The equivalent precision of the PMM for the LCS dataset compared to the mass spectrometry PMM is therefore as a result of an inconsistent dataset (χ^2/ν = 1.65).

11.11 Gross alpha and gross beta results for AB, A1 and B1

Gross alpha and beta measurements are used to screen for radioactivity in samples (ISO 10704:2019; ISO 11704:2018) and are not suitable for absolute determination of the activity per unit mass of all alpha and beta emitting radionuclides. Gross alpha and beta measurements are employed to ensure reference levels of specific alpha- and beta-emitting particles have not been exceeded. Gross alpha and gross beta analysis are not expected to be as accurate nor as precise as specific radionuclide analysis after radiochemical separations.

The Assigned Values of gross measurements for the AB, A1 and B1 sample types is determined using the PMM of the participants results. This method is well suited to most data sets but assumes a basic level of competency and relies on being protected against erroneous and extreme data through correction or exclusion (Pommé, 2015). NPL did not specify a standard method for gross alpha or beta analysis resulting in an array of measurement techniques being adopted. A small number of results (< 8) were submitted for each gross measurement. Inconsistencies were observed between measurement results and the mean making the identification of extreme data impossible. An inability to handle extreme data lead to low confidence in the PMM derived for gross beta measurements. In some instances it was also unclear if measurements provided were true gross beta measurements, taking into account both high energy and low energy beta emitters and in no instances was it stated whether equilibrium had been established prior to measurement. It is for these reasons that NPL has decided not to formally declare Assigned Values for the gross beta measurements of AB and B1 sample type. The PMM results for gross beta measurements have been included as a point of reference and the performance criteria for these measurements should be disregarded. Although no Assigned Values have been provided for gross beta measurements laboratories may refer to values of individual radionuclides to assess their own methods internally.

Only six results were provided for gross beta in the AB sample type, three using proportional counting (PC), one by LSC and one using a Geiger-Muller (GM) tube. The PMM for the gross beta in the AB sample was (10.9 ± 2.0) Bq g^{-1}. The AB sample contained the beta-emitting radionuclides ^{63}Ni, ^{90}Sr (^{90}Y), ^{147}Pm with Beta end-point energies of 66.98 keV, 545.9 keV (2278.7 keV) and 224.1 keV respectively as well as the alpha-emitting radionuclide ^{238}Pu. Table 8 shows the participants' results alongside the measurement technique stated in the report form. Note that the laboratory activities listed in Tables 8-10 are stated as reported.

Table 8 Table linking laboratory activities to the PMM and measurement techniques for gross beta measurements in the AB sample type.

Laboratory Code	Laboratory Activity (Bq g^{-1})	Measurement Technique
1	9.70 ± 1	PC
7	18.50 ± 1.4	LSC
8.1	8.11 ± 0.05	PC
38	7.60 ± 0.6	PC
55	11.10 ± 1.48	GM
173	32.84 ± 3.1681	Not provided

For the A1 gross alpha, six results were submitted. Techniques included alpha spectrometry (2), alpha scintillation (ASc) with ZnS screen (1), LSC with alpha beta discrimination (1) and PC (2). Two participants used ^{241}Am standards as counting standards for both LSC and PC. The proportional counting measurements gave results with negative deviations from the Assigned Value.

Table 9 Table linking laboratory activities to the PMM and measurement techniques for gross alpha measurements in the A1 sample type.

Laboratory Code	Laboratory Activity (Bq g^{-1})	PMM (Bq kg^{-1})	Zeta	Measurement Technique
1	25.7 ± 1.7	30.5 ± 1.8	-1.94	PC
7	33.3 ± 1.9		1.07	LSC
8.1	28.1 ± 0.51		-1.28	ASc
38	11 ± 2		-7.25	PC
86.1	33.64492247 ± 3.364492247		0.82	AS
91	34.6 ± 3.5		1.04	Not provided

Results of the B1 gross beta sample type resulted in the largest data spread, with reported activities ranging from 0.099 Bq g^{-1} to 1.03 Bq g^{-1}. The PMM for the gross beta emissions in the B1 sample was (0.48 ± 0.13) Bq g^{-1}. Measurements were made using PC (1) and LSC (4). Proportional counters are usually operated in the “windowed” mode for the detection of beta-emitting radionuclide with emission energies > 0.1 MeV and should be switched to a “windowless” to detect low energy beta emitters such as ^{3}H. Laboratory 8 provided two measurements for gross beta using LSC, one using a ^{3}H window and one with ^{14}C. The measurement using a ^{14}C window provided a result around 50% lower than that of the ^{3}H window indicating a loss of counts. In this instance two methods appear to have been provided for the screening of ^{3}H and ^{14}C independently of one another. Laboratories 109.1 and 38 also provided results comparable to that of the ^{14}C window result. Laboratory 7 stated that use of a ^{3}H and ^{99}Tc standard and provided results similar to the ^{3}H window result of laboratory 8. In preparation of proportional counting deposits, it is also important to consider potential loss of volatile radionuclides including ^{3}H and ^{14}C during any heating method that may be used. That being said the apparent loss of counts in this instance is likely attributable to window selection and not volatility issues.

Table 10 Table linking laboratory activities to the PMM and measurement techniques for gross beta measurements in the B1 sample type.

Laboratory Code	Laboratory Activity (Bq g^{-1})	Measurement Technique
1	0.099 ± 0.018	PC
7	0.884 ± 0.069	Not provided
8.1	1.03 ± 0.03	LSC
8.2	0.454 ± 0.014	Not provided
38	0.277 ± 0.009	LSC
109.1	0.3522 ± 0.0528	LSC
159	0.2762 ± 0.02055	Not provided

11.12 Sample Types GH and GL

A similar number of datasets were provided for the 2019 as for the 2018 exercise. Both samples included radionuclides with a wide range of emission energies. The GL sample for this year's exercise contained challengingly low-levels of ^{241}Am and ^{210}Pb. This resulted in a lower number of results being provided for ^{210}Pb. As was stated in the 2018 exercise report, ^{210}Pb is difficult to measure due to the presence of ^{210}Pb in background measurements and correctly determining the self-attenuation correction factors. The results from the GH and GL sample types is summarised in Table 11 below.

Table 11 Results classification summary table for GH and GL sample types.

Sample Type	Radionuclide	Results Submitted			
		In agreement	Questionable	Discrepant	Total
GH	^{22}Na	24	4	3	31
	^{54}Mn	27	4	0	31
	^{133}Ba	28	1	2	31
	^{137}Cs	31	2	0	31
GL	^{58}Co	25	2	3	30
	^{134}Cs	26	5	1	32
	^{210}Pb	9	10	3	22
	^{241}Am	25	6	4	35

The majority of measurements for the GH and GL sample types were carried out by high resolution gamma spectrometry. However, results for ^{241}Am provided some variation in detection techniques with three laboratories opting for alpha spectrometry and one for ICP-MS. Of the alternate techniques provided, alpha spectrometry results accounted fortwo of the three questionable results, and the mass spectrometry result was discrepant. Direct measurement of ^{241}Am by ICP-MS is very challenging at this activity concentration and would require pre-concentration prior to measurement, using ^{243}Am as a yield tracer.

Some laboratories consistently reported higher or lower values than the NPL reference value for all the reported radionuclides and this may be due to various reasons. The most probable of these is that the calibration used for the full-energy detection efficiency may be inaccurate. The calibration used for the full-energy detection efficiency also may not include calibration points below 60 keV, which may cause additional uncertainty and potential errors when measuring radionuclides with emission energies < 60 keV, such as ^{210}Pb.

For the case of ^{133}Ba and ^{22}Na an overall negative bias for the participants can be seen against the NPL reference value. This is most likely attributable to an underestimation of the True Coincidence Summing (TCS). This phenomenon is where two photons (or more) arising

from the same disintegration interact with the detector simultaneously, removing counts from the full energy peaks of the interacting photons. For ^{22}Na this would mainly occur from the simultaneous detection of the 1274 keV gamma ray and the 511 keV photon arising from annihilation of the positron emission, a similar case is also observable for ^{58}Co. In the cases of ^{133}Ba and ^{134}Cs the principal gamma rays are in coincident with another gamma ray.

All questionable results for ^{54}Mn were from laboratories quoting relative uncertainties ranging between 1-3 % which were lower than the mean (6 %). For ^{137}Cs two questionable results were submitted, of these one had a low relative uncertainty (1 %) and deviation of (13%) causing it to fail zeta test which the other was in good agreement with the Assigned Value (deviation, 3.3%) but had a significantly overestimated relative uncertainty (56 %).

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