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ENVIRONMENTAL RADIOACTIVITY PROFICIENCY TEST EXERCISE 2021

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Environmental Radioactivity Proficiency Test Exercise 2021

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ABSTRACT

The results of NPL's twenty-seventh Environmental Radioactivity Proficiency Test Exercise are reported. Five different sample types were offered: an aqueous mixture of one alpha-emitting radionuclide and two 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 three gamma-emitting radionuclides ('GH'), and a second aqueous mixture of five gamma-emitting radionuclides ('GL'). In total, 489 results were submitted.

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

Assigned Values (reference time 2021-06-01 12:00:00 UTC)

Radionuclide (AB)	Assigned Value (Bq g^{-1})
^{3}H	14.22 ± 0.15
^{90}Sr	6.266 ± 0.016
^{241}Am	7.761 ± 0.031
^{244}Cm	5.0547 ± 0.0073
Radionuclide (A1)	**Assigned Value (Bq kg^{-1})**
^{238}U	4.861 ± 0.083
^{238}Pu	2.1690 ± 0.0054
^{241}Am	15.841 ± 0.067
Radionuclide (B1)	**Assigned Value (Bq g^{-1})**
^{3}H	0.5885 ± 0.0081
^{14}C	0.4769 ± 0.0044
^{99}Tc	0.2076 ± 0.0025
Radionuclide (GH)	**Assigned Value (Bq g^{-1})**
^{54}Mn	5.091 ±0.029
^{60}Co	2.3900 ±0.0095
^{65}Zn	2.612 ± 0.023
^{133}Ba	28.26 ± 0.20
^{137}Cs	39.72 ± 0.29
Radionuclide (GL)	**Assigned Value (Bq kg^{-1})**
^{134}Cs	10.600 ± 0.076
^{137}Cs	6.733 ± 0.061
^{210}Pb	23.94 ± 0.25
^{241}Am	23.83 ± 0.10

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-seventh in a series of annual exercises run by NPL over the last 30 years. These exercises help analysts to identify metrology challenges and support UKAS accreditations in the quantification of radionuclides. A range of sample types were made available during previous exercises. These have been mostly aqueous but have on occasion included solid materials, which have been introduced subject to availability. This exercise consisted of aqueous solutions only with five sample types made available to the participants, summarised in Table 1.

Table 1 Summary of samples available to the participants for this proficiency test exercise.

Sample type	Sample type code	Contents	Nominal Mass supplied	Activity range
Alpha Beta	AB	Two alpha- and two beta-emitting radionuclides in dilute nitric acid	20 g	1–20 Bq g^{-1}
Alpha One	A1	Three‡ alpha-emitting radionuclides in dilute nitric acid	500 g	1–20 Bq kg^{-1}
Beta One	B1	Three beta-emitting radionuclides in 0.01 M NaOH solution	500 g	0.1–1 Bq g^{-1}
Gamma High	GH	Five gamma-ray emitting radionuclides in dilute nitric acid	100 g	1–50 Bq g^{-1}
Gamma Low	GL	Four gamma-ray emitting radionuclides in dilute nitric acid	500 g	1–50 Bq kg^{-1}

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 identified and quantified the activity per unit mass of the radionuclides present in the samples. NPL then collected, analysed, and interpreted the results which were compiled into a report.

Each participant was allocated by NPL a unique laboratory code number (if not already allocated in a previous PTE in this series). This was done in confidence so that no third parties could identify the participants by their allocated code number. The participants were asked to add their code numbers to their Reporting Forms, and the code numbers would 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 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 either liquid scintillation counting or high-purity germanium (HPGe) gamma spectrometry. The Assigned Value for each radionuclide was calculated from the division of the standardised activity per unit mass of the original standard solution by the dilution factor(s). The activities per unit mass of the radionuclides in the

‡The A1 sample type contained U-Nat but participants were only asked to report for ^{238}U.

aqueous sample types were traceable to national standards of radioactivity, and therefore to the international measurement system.

The standard uncertainty of the Assigned Values for each radionuclide was derived from the uncertainty components attributed to the activity of the standardised parent solution, the gravimetric dilution and the decay correction to the reference time. These uncertainties have been evaluated and validated in accordance with the requirements of UKAS.

Throughout this report, 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 %.

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.

Participants' data were analysed to provide the deviation, and the associated stand uncertainty, from the assigned value. The participants' performance was then assessed using the method described in section 2.

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

There were no cases where the PMM was used as the Assigned Value. Note that consensus values based on the PMM are not traceable to national standards of radioactivity. The PMM of the gross measurements is provided as an indicator and has not been used for performance assessment. It is for this reason results for gross measurements do not appear in the main body of the report. The gross measurements are given in APPENDIX I.

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

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

2. TREATMENT OF DATA

The data were analysed using the same methods as in the 2020 exercise (van Es et al., 2021). The deviation '*D*' from the assigned value from each laboratory value was calculated from:

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

The standard uncertainty 'u_D' of the deviation was calculated from:

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

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

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

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

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

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 13528:2015 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 % will pass the z-test.

Note that the z-score presented is as defined in ISO 13528:2015 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 the deviation is less than 15% from the Assigned Value but the standard uncertainty is insufficient result in agreement with the Assigned Value), 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.

A result was only classified as 'in agreement' when the three tests (the zeta test, the relative uncertainty outlier test and the *z*-test) were passed. A failure to pass one of these tests resulted in a classification 'questionable'. Failure of both the zeta test and the *z*-test resulted in a classification 'discrepant'. The classification criteria used to assess the performance of participants are summarised in Table 2.

Table 2 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 summary of classification results for each radionuclide in each sample type is provided in Table 3. The number of no results is for indication only and does not relate to a failed result as it is considered that all radionuclides in a sample may not be relevant for a particular participant and that they have only reported for those radionuclides relevant to their test regimes.

Table 3 Summary of classifications for each radionuclide in each sample type

Radionuclide	Samples despatched	Pass	Questionable	Fail	No result
AB					
^{3}H	26	18	1	2	4
^{90}Sr		19	2	0	2
^{241}Am		18	0	0	6
^{244}Cm		13	2	1	6
A1					
^{238}U	21	14	1	1	5
^{238}Pu		12	3	3	2
^{241}Am		12	3	4	2
B1					
^{3}H	34	25	4	2	4
^{14}C		18	3	2	9
^{99}Tc		14	1	1	16
GH					
^{54}Mn	34	32	3	1	0
^{60}Co		33	3	0	0
^{65}Zn		32	2	2	0
^{133}Ba		30	3	2	0
^{137}Cs		34	1	1	0

Radionuclide	Samples despatched	Pass	Questionable	Fail	No result
GL					
^{134}Cs	29	25	4	1	0
^{137}Cs		28	2	0	0
^{210}Pb		13	6	3	8
^{241}Am		25	4	0	1

In addition to the analyses of individual participants' data as described in Section 2, the PMM of the reported results for each radionuclide was compared with the NPL Assigned Values. The results are given in Tables 4 - 8. The tests as described in section 2 are used to assess the agreement between these values. The reference time is 2021-06-01 12:00:00 UTC.

Table 4 AB summary

Radionuclide	NPL Assigned Values (Bq g^{-1})	PMM (Bq g^{-1})	Deviation %	Zeta	Critical Value
^{3}H	14.22 ± 0.15	13.63 ± 0.73	−4.1	−0.79	2.82
^{90}Sr	6.266 ± 0.016	6.312 ± 0.077	0.7	0.58	2.82
^{241}Am	7.761 ± 0.031	7.594 ± 0.078	−2.1	−1.99	2.81
^{244}Cm	5.0547 ± 0.0073	4.768 ± 0.095	−5.7	−3.01	2.95

Table 5 A1 summary

Radionuclide	NPL Assigned Values (Bq kg^{-1})	PMM (Bq kg^{-1})	Deviation %	Zeta	Critical Value
^{238}U	4.861 ± 0.083	4.72 ± 0.11	−2.9	−1.01	2.72
^{238}Pu	2.1690 ± 0.0054	2.196 ± 0.088	1.3	0.31	2.90
^{241}Am	15.841 ± 0.067	14.13 ± 0.70	−10.8	−2.44	2.88

Table 6 B1 summary

Radionuclide	NPL Assigned Values (Bq g^{-1})	PMM (Bq g^{-1})	Deviation %	Zeta	Critical Value
^{3}H	0.5885 ± 0.0081	0.581 ± 0.020	−1.3	−0.35	2.70
^{14}C	0.4769 ± 0.0044	0.446 ± 0.015	−6.5	−1.97	2.78
^{99}Tc	0.2076 ± 0.0025	0.234 ± 0.039	12.7	0.67	2.95

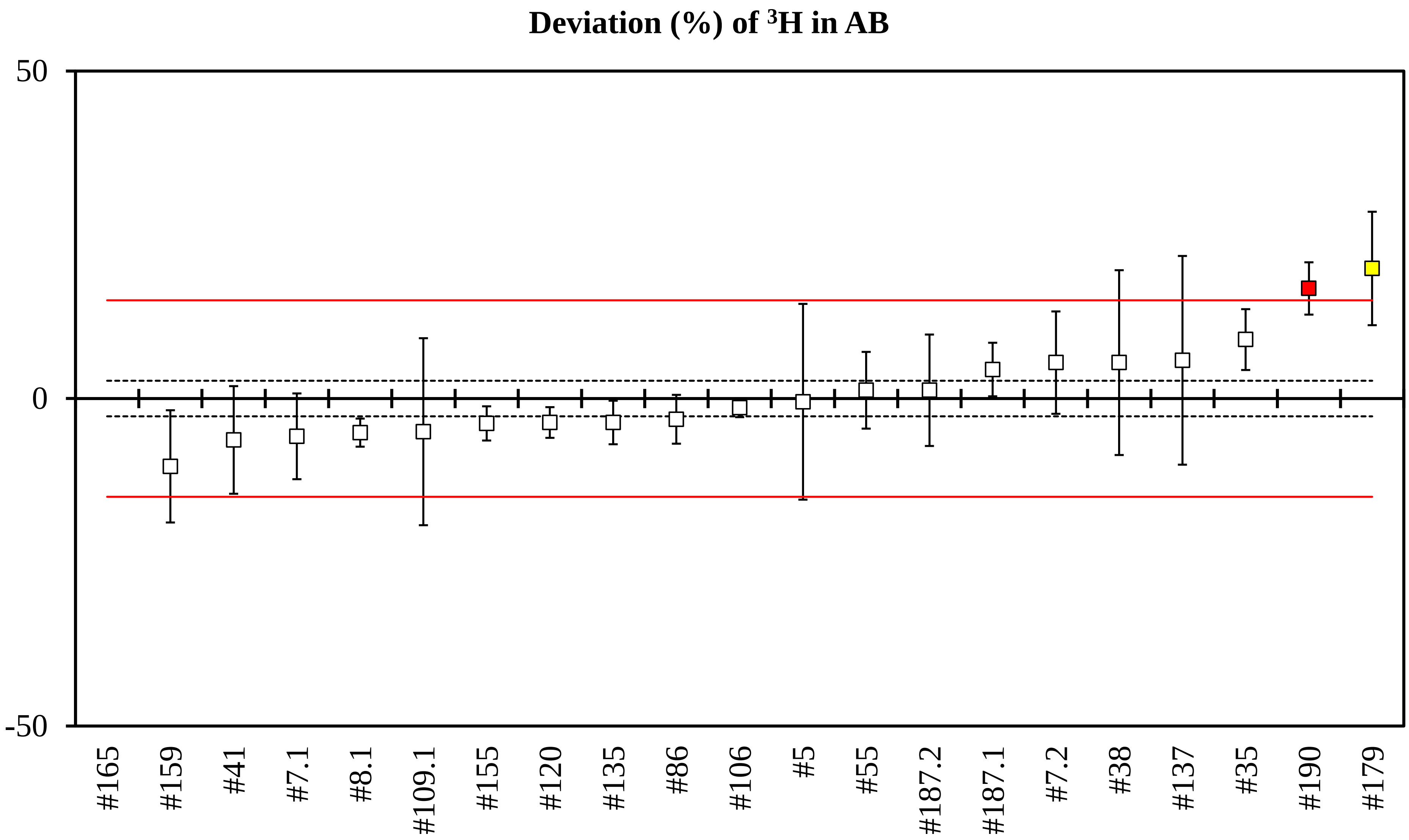
Table 7 GH summary

Radionuclide	NPL Assigned Values (Bq g^{-1})	PMM (Bq g^{-1})	Deviation %	Zeta	Critical Value
^{54}Mn	5.091 ±0.029	5.042 ± 0.090	−1.0	−052	2.70
^{60}Co	2.3900 ±0.0095	2.373 ± 0.020	−0.7	−0.77	2.67
^{65}Zn	2.612 ± 0.023	2.618 ± 0.056	0.2	0.09	2.68
^{133}Ba	28.26 ± 0.20	27.80 ± 0.62	−1.6	−0.71	2.70
^{137}Cs	39.72 ± 0.29	39.37 ± 0.46	−0.9	−0.65	2.65

Table 8 GL summary

Radionuclide	NPL Assigned Values (Bq kg^{-1})	PMM (Bq g^{-1})	Deviation %	Zeta	Critical Value
^{134}Cs	10.600 ± 0.076	10.27 ± 0.14	−3.1	−2.04	2.69
^{137}Cs	6.733 ± 0.061	6.890 ± 0.068	2.3	1.72	2.63
^{210}Pb	23.94 ± 0.25	20.73 ± 0.51	−13.4	−5.66	2.74
^{241}Am	23.83 ± 0.10	24.21 ± 0.31	1.6	1.15	2.73

4. ALPHA BETA (AB) DEVIATION PLOTS


Deviation (%) of ³H in AB
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#41
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#109.1
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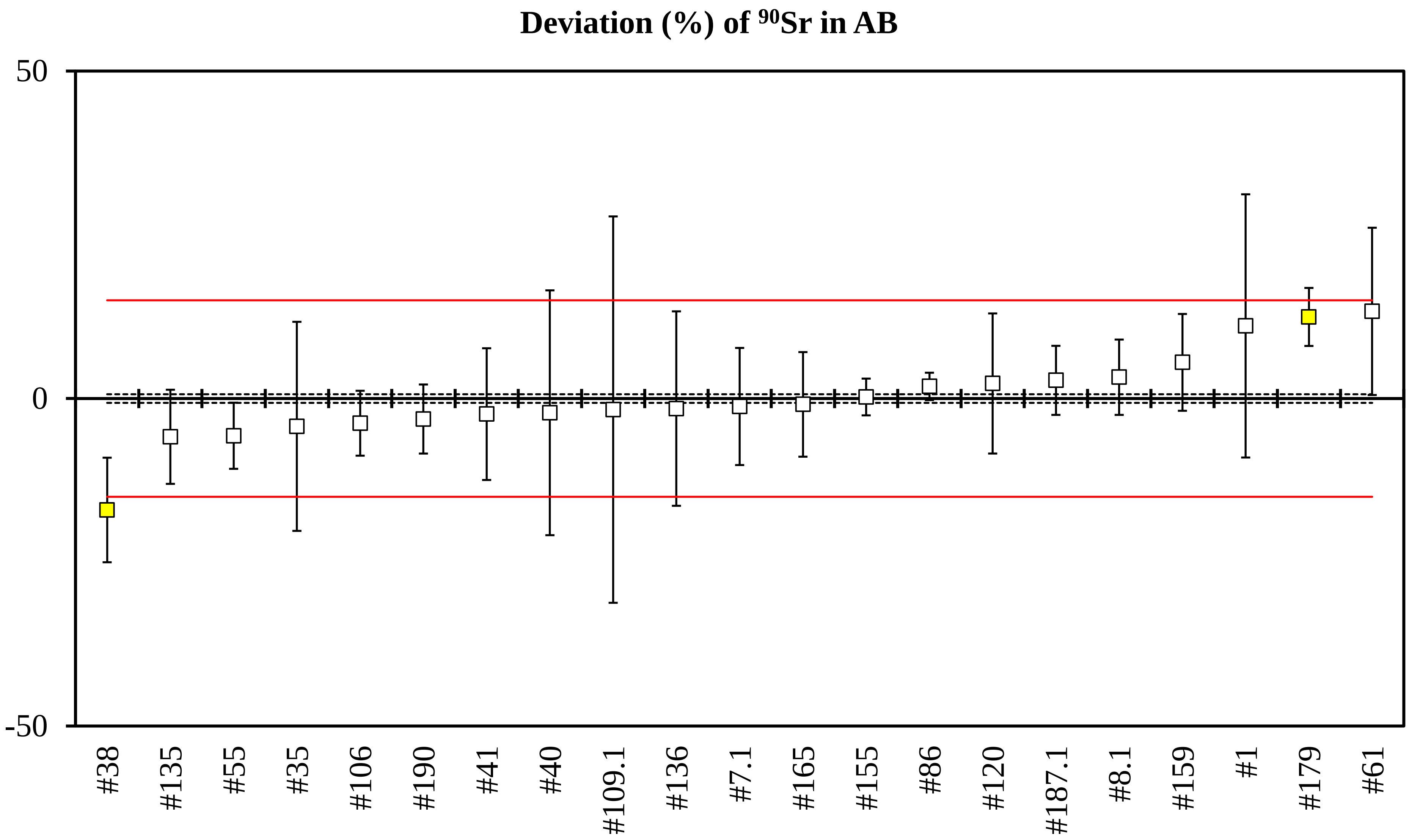
#190
#179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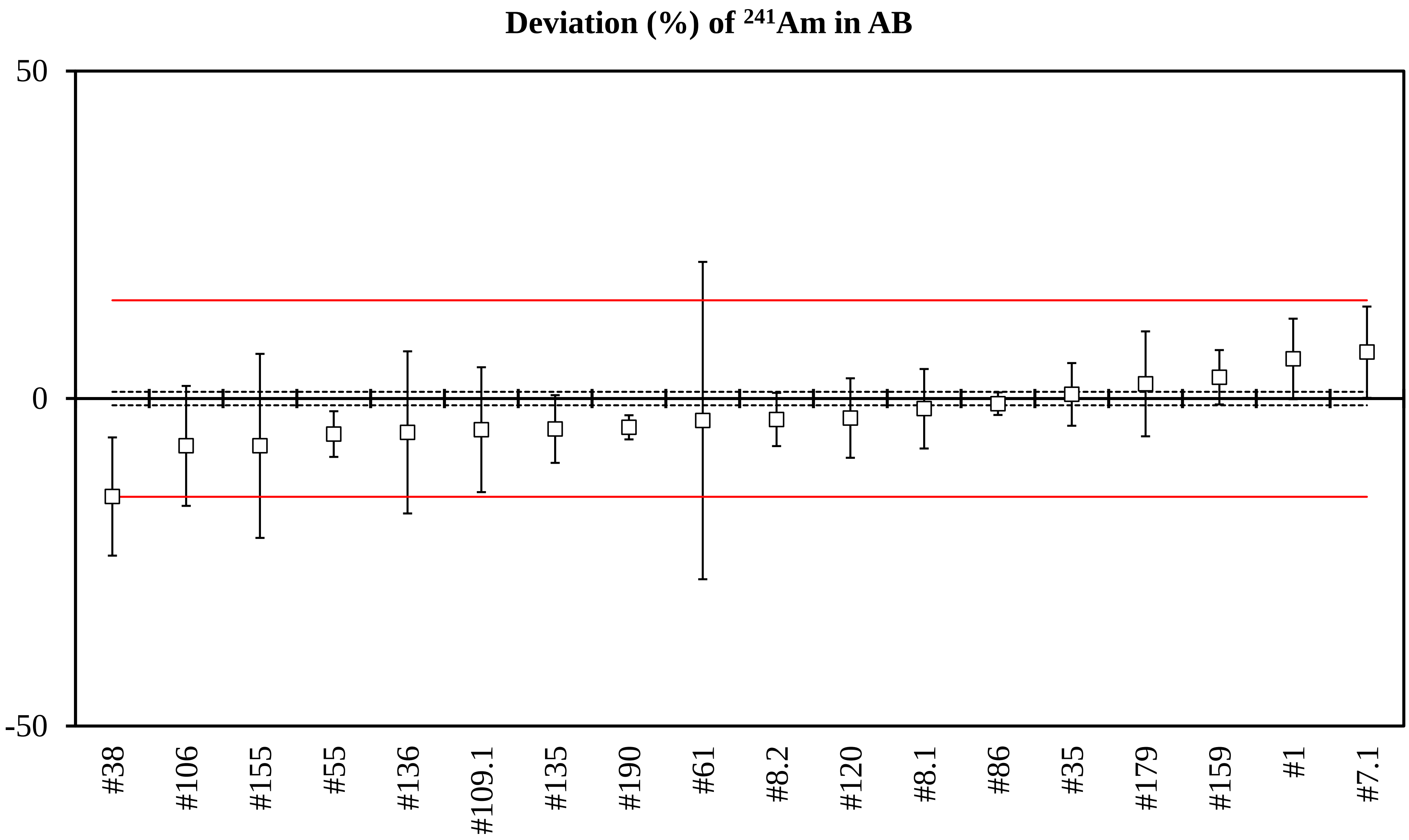
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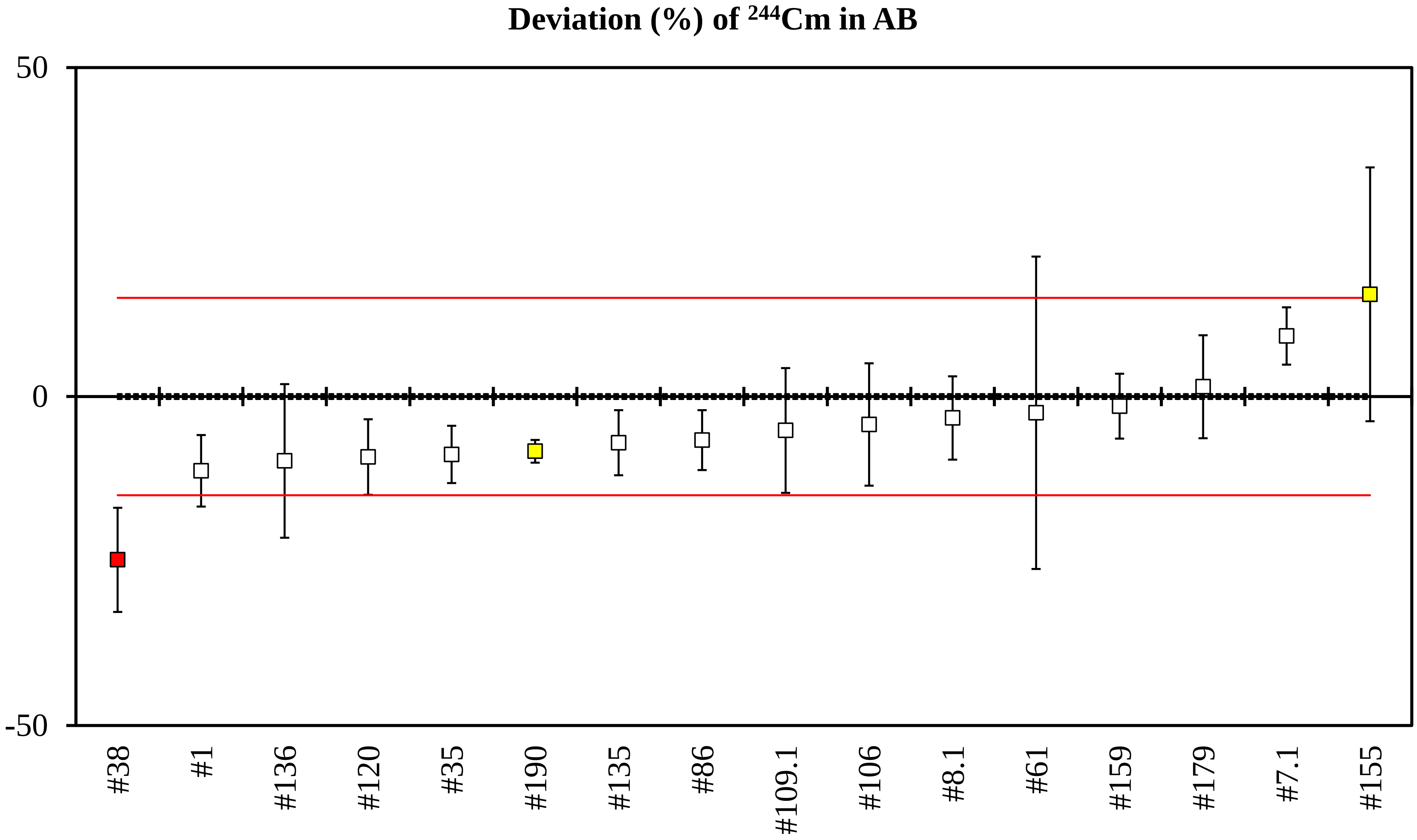
Deviation (%) of 244Cm in AB
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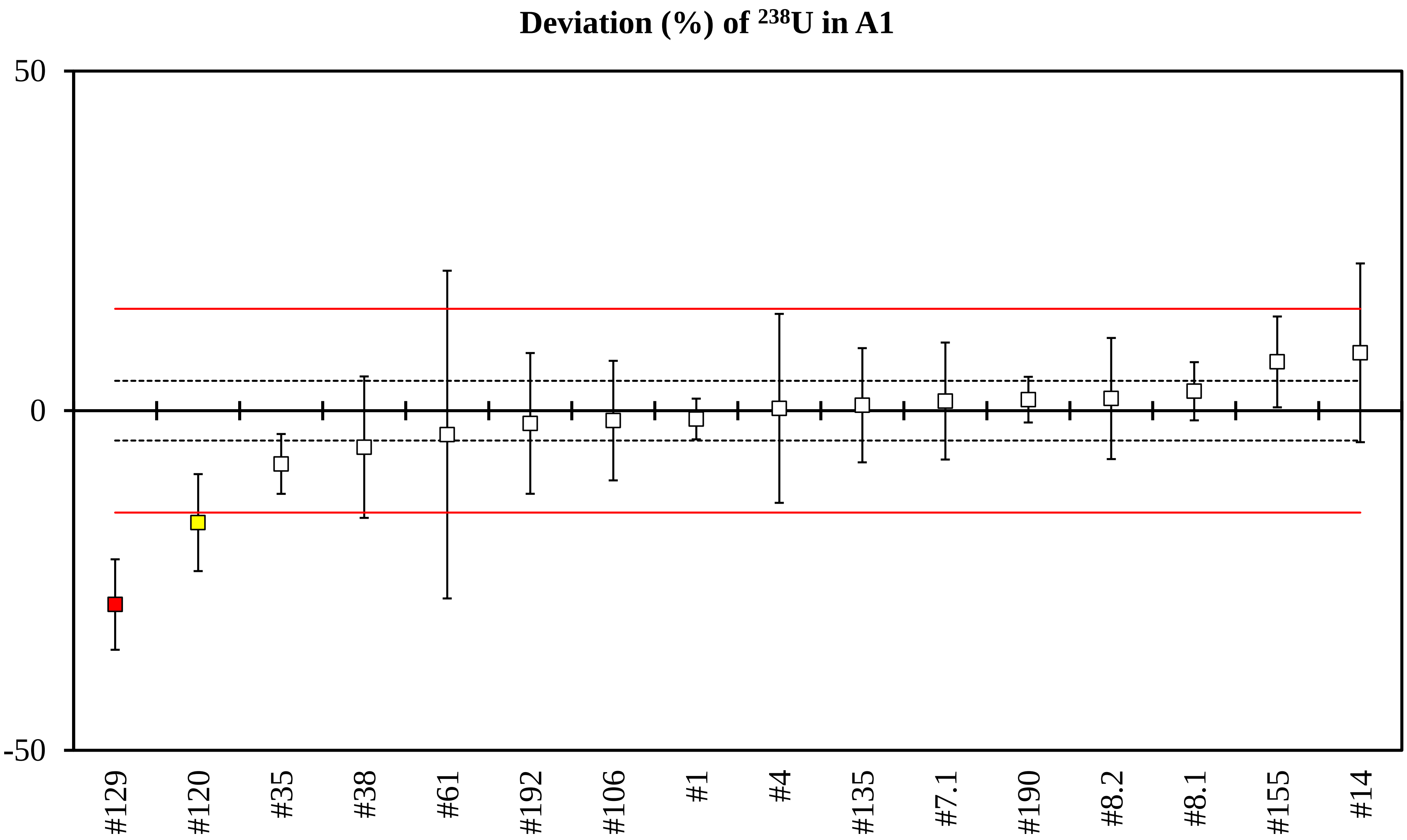
#179
#7.1
#155

5. ALPHA ONE (A1) DEVIATION PLOTS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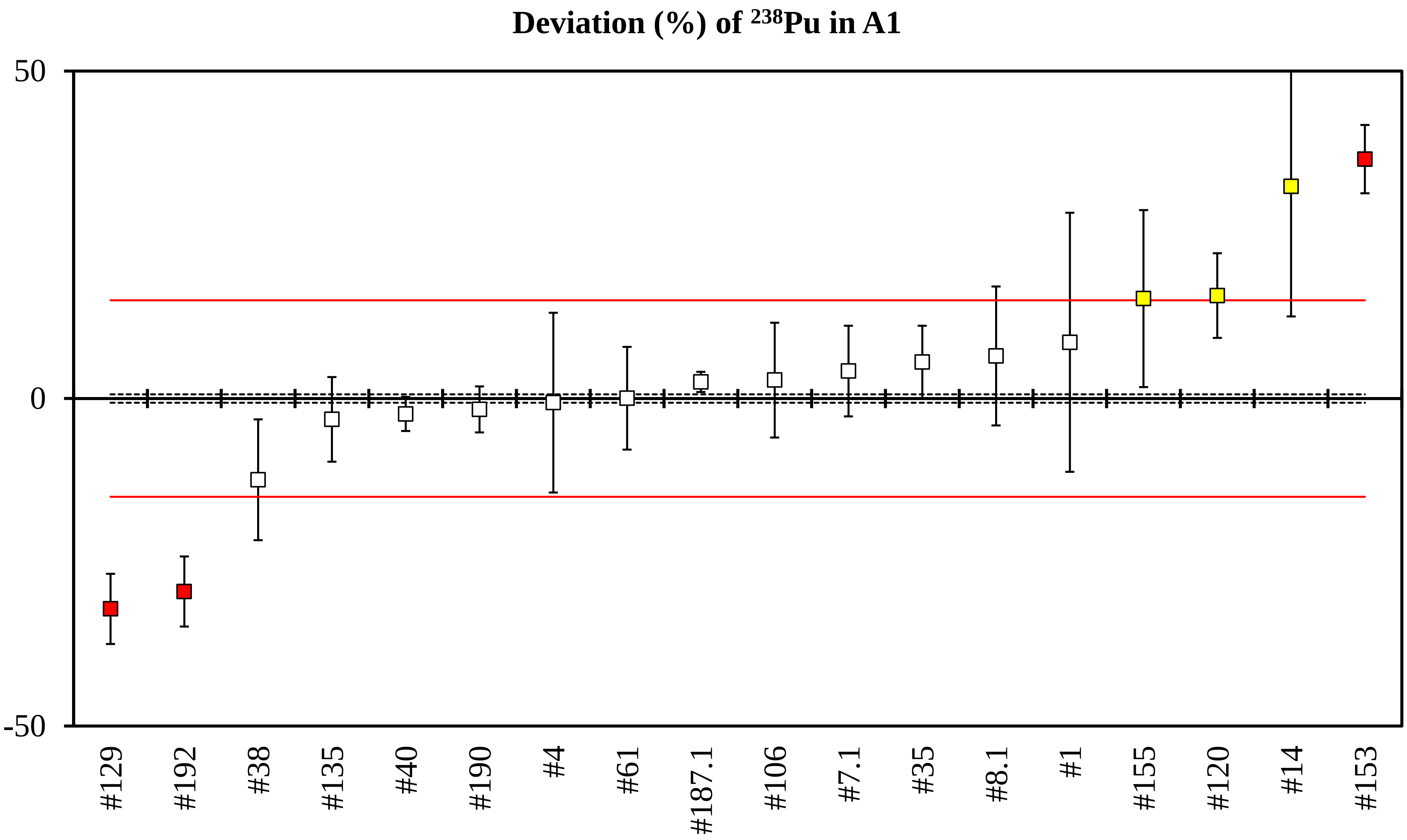
#14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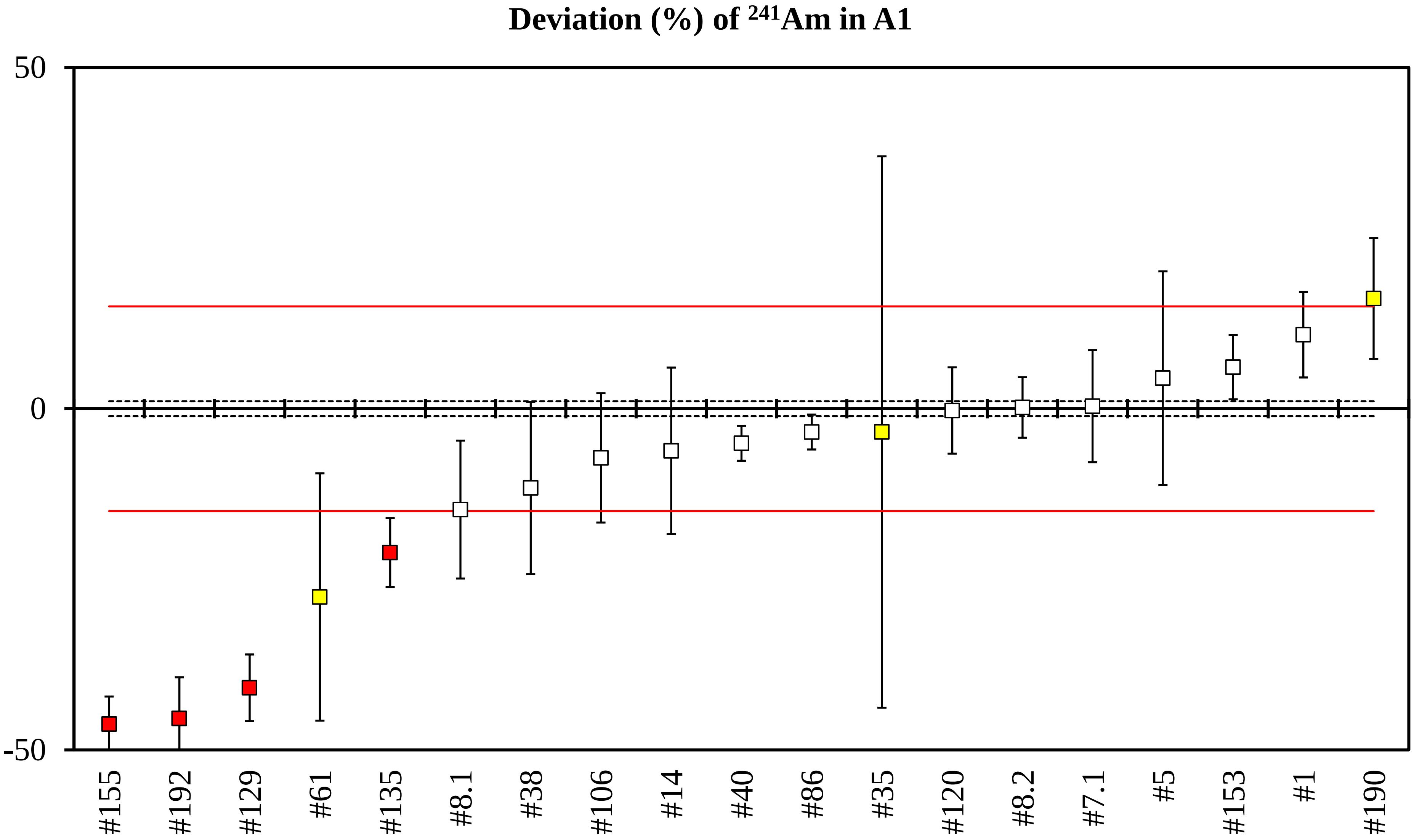
#14
#153


Deviation (%) of 241Am in A1
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#61
#135
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#14
#40
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#8.2
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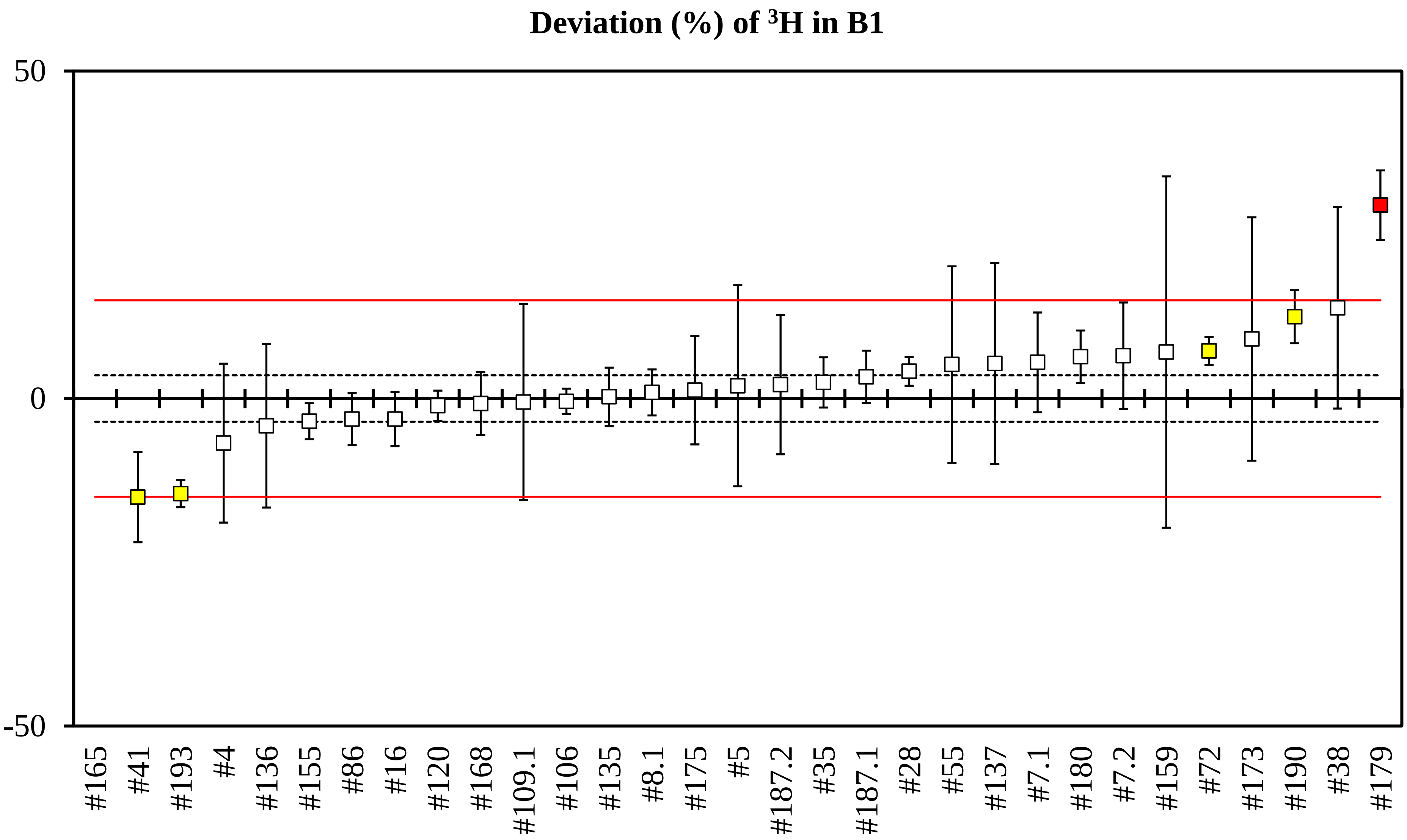
#153
#1
#190

6. BETA ONE (B1) DEVIATION PLOTS



Deviation (%) of ^{3}H in B1
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#41
#193
#4
#136
#155
#86
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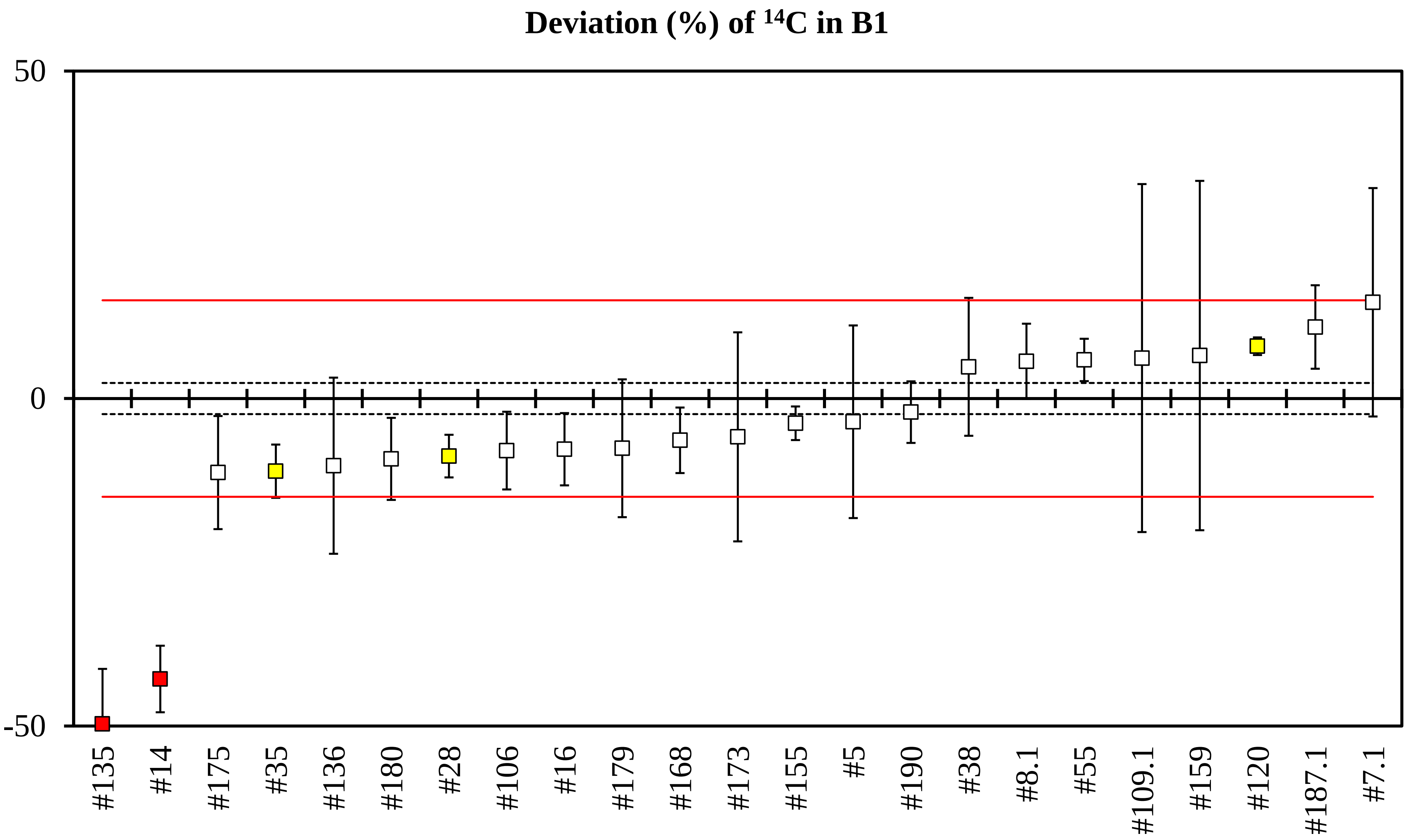
#173
#190
#38
#179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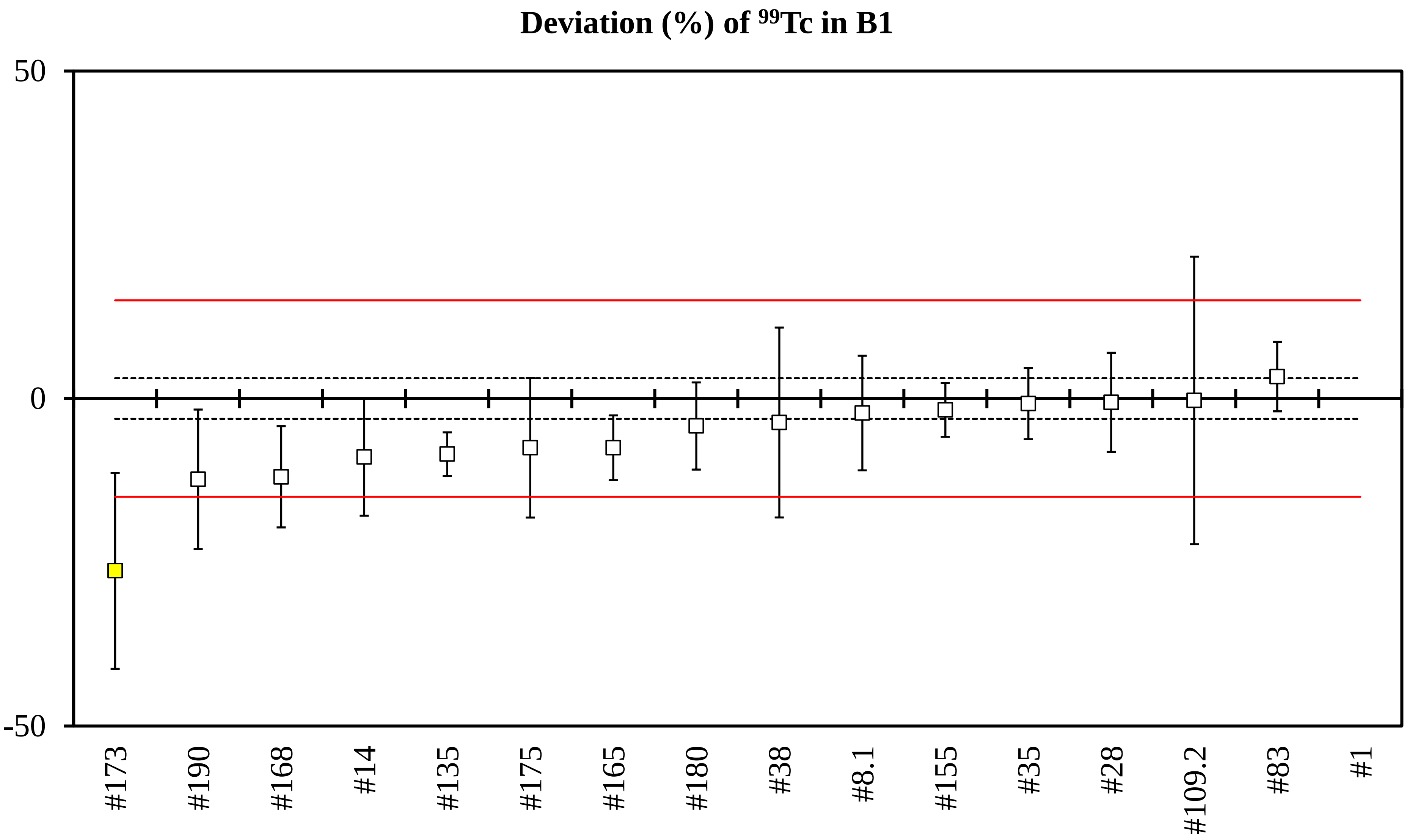

Deviation (%) of ^{99}Tc in B1
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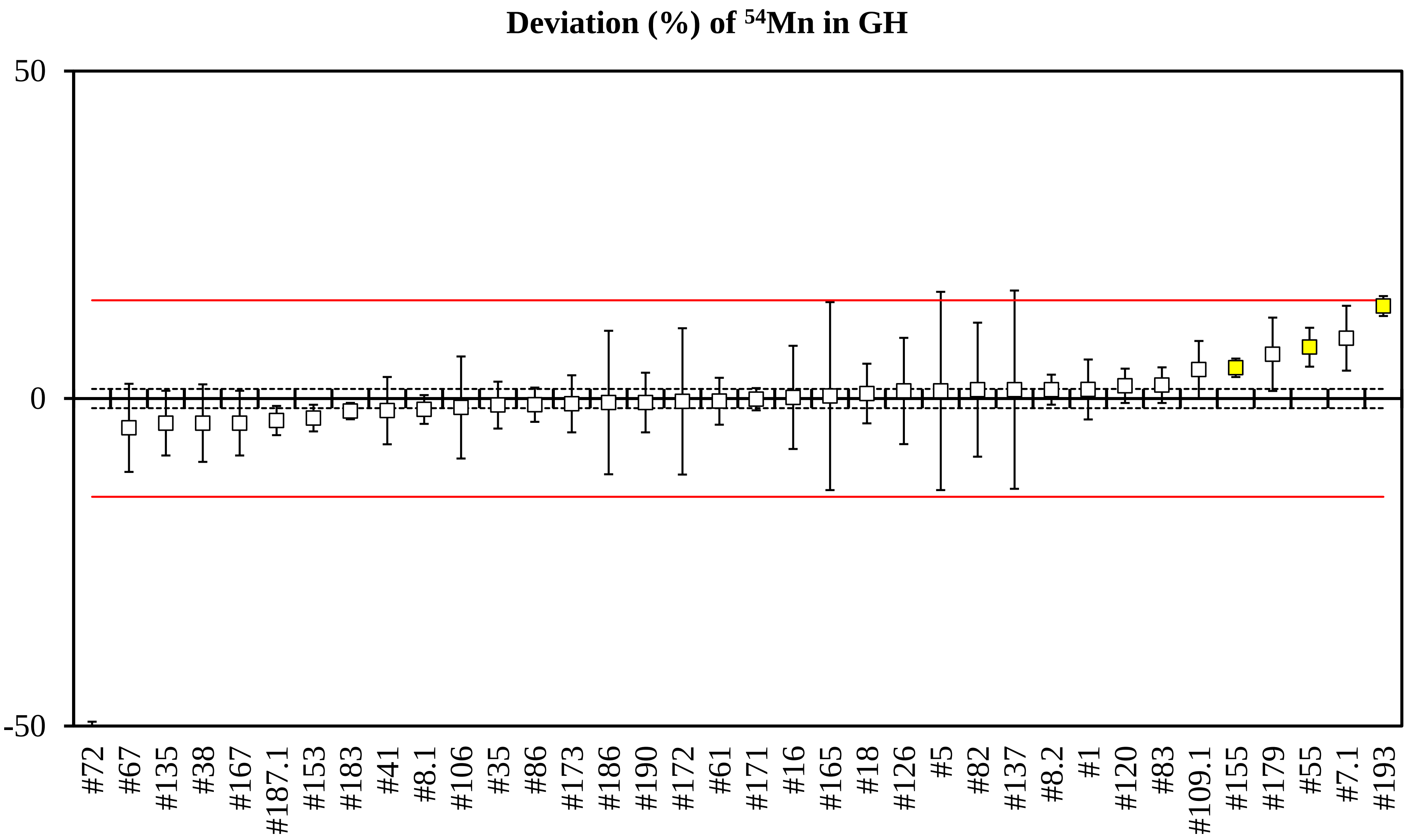
7. GAMMA HIGH (GH) DEVIATION PLOTS


Deviation (%) of 54Mn in GH
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#82
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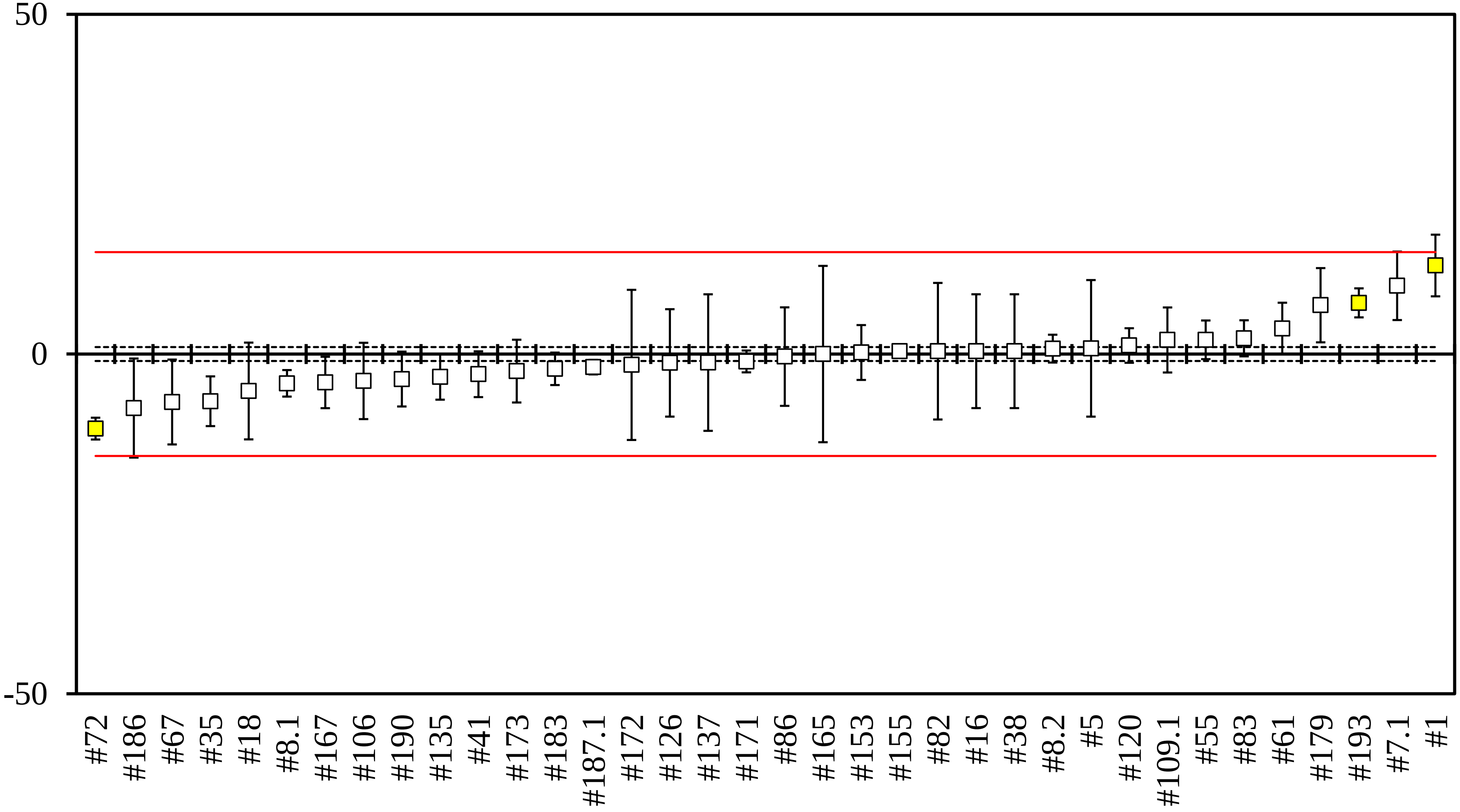
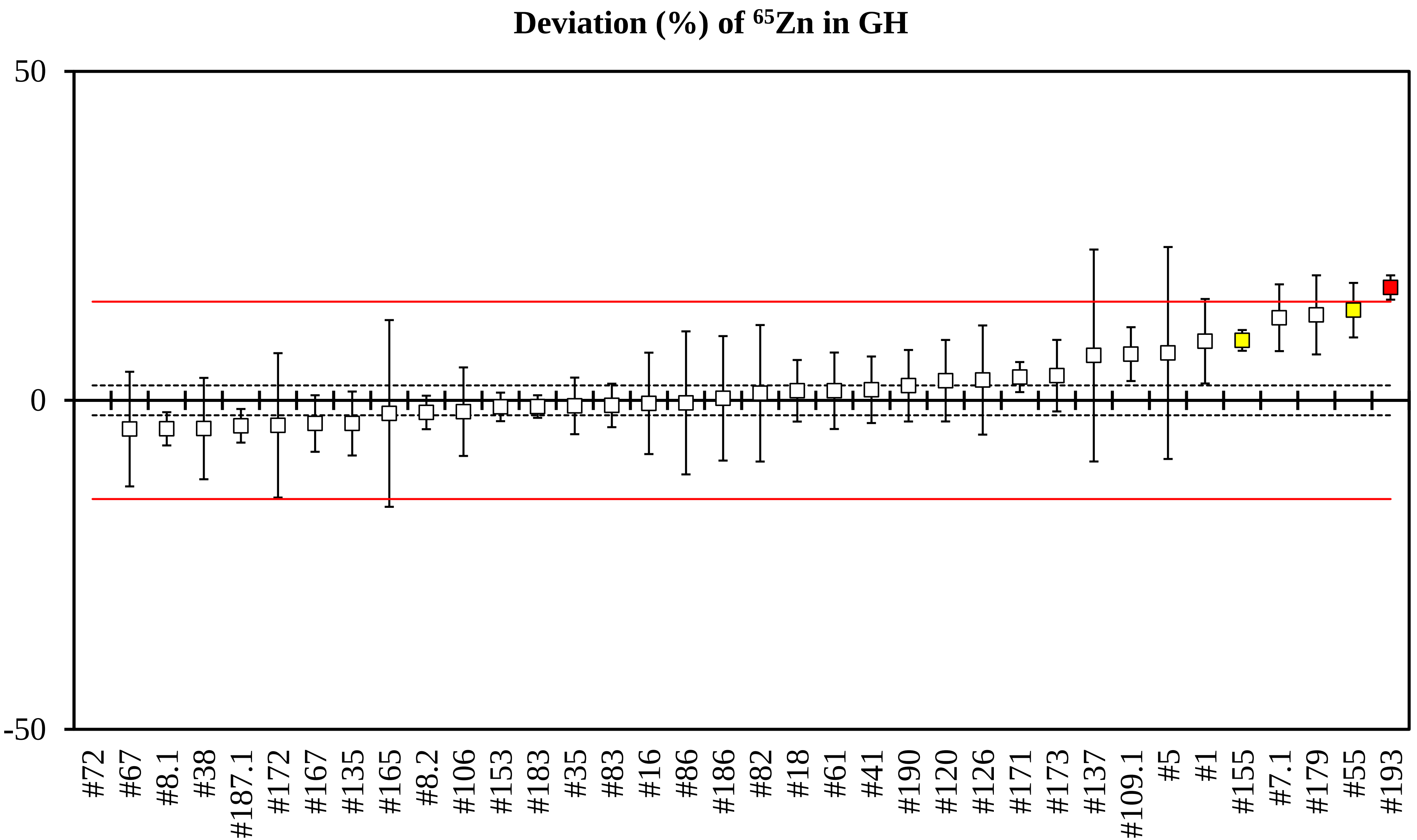
Deviation (%) of ^{60}Co in GH

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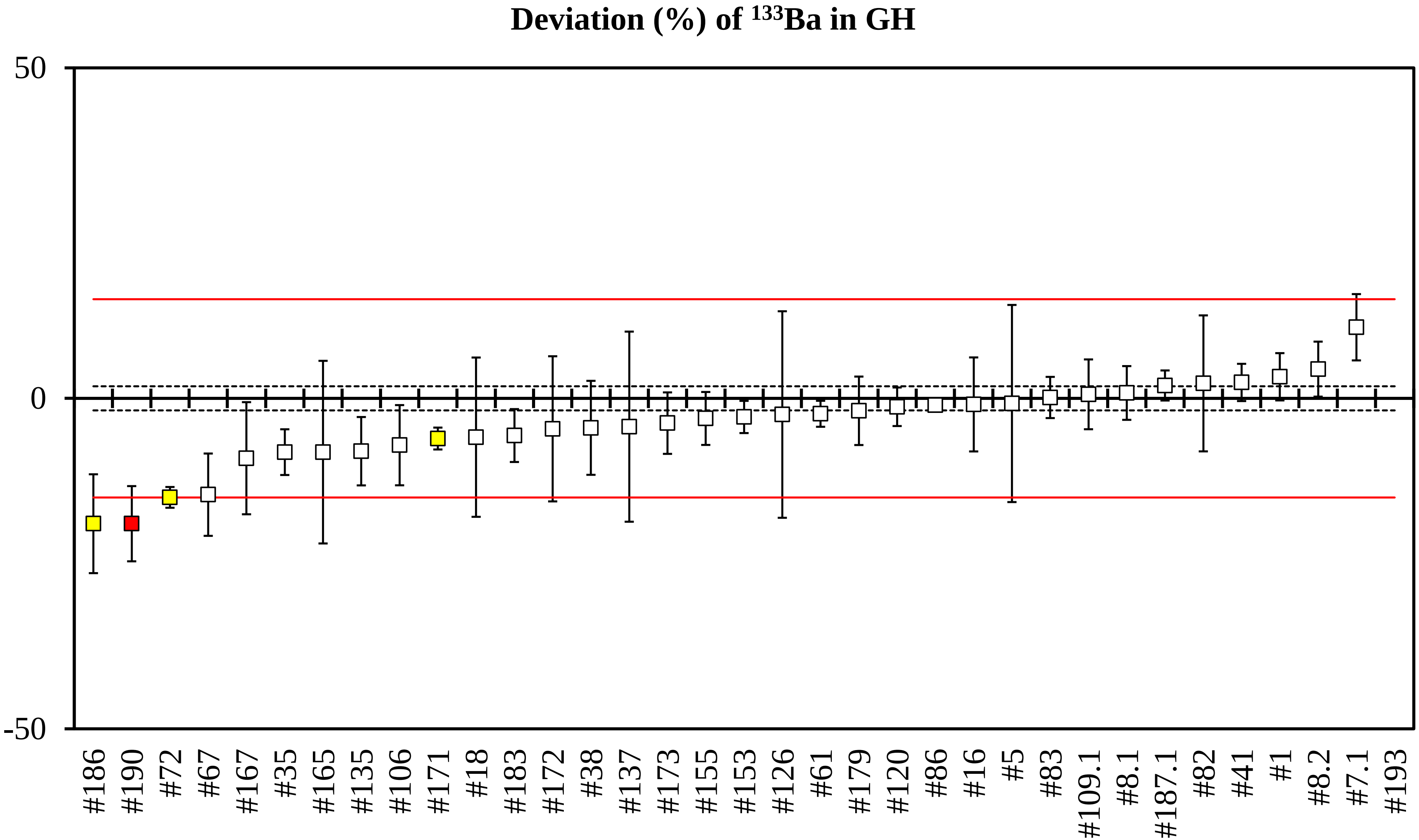
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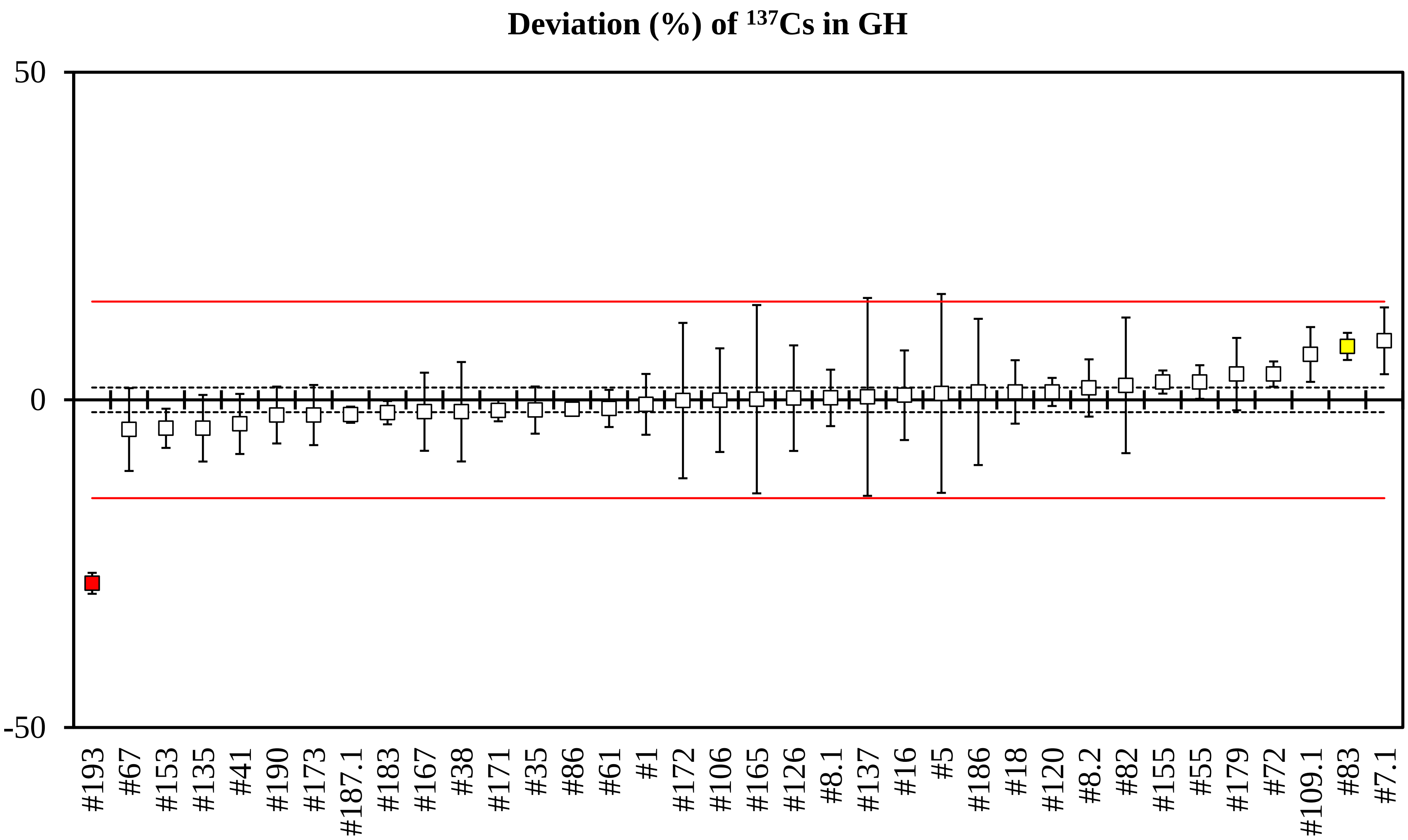
Deviation (%) of ^{137}Cs in GH
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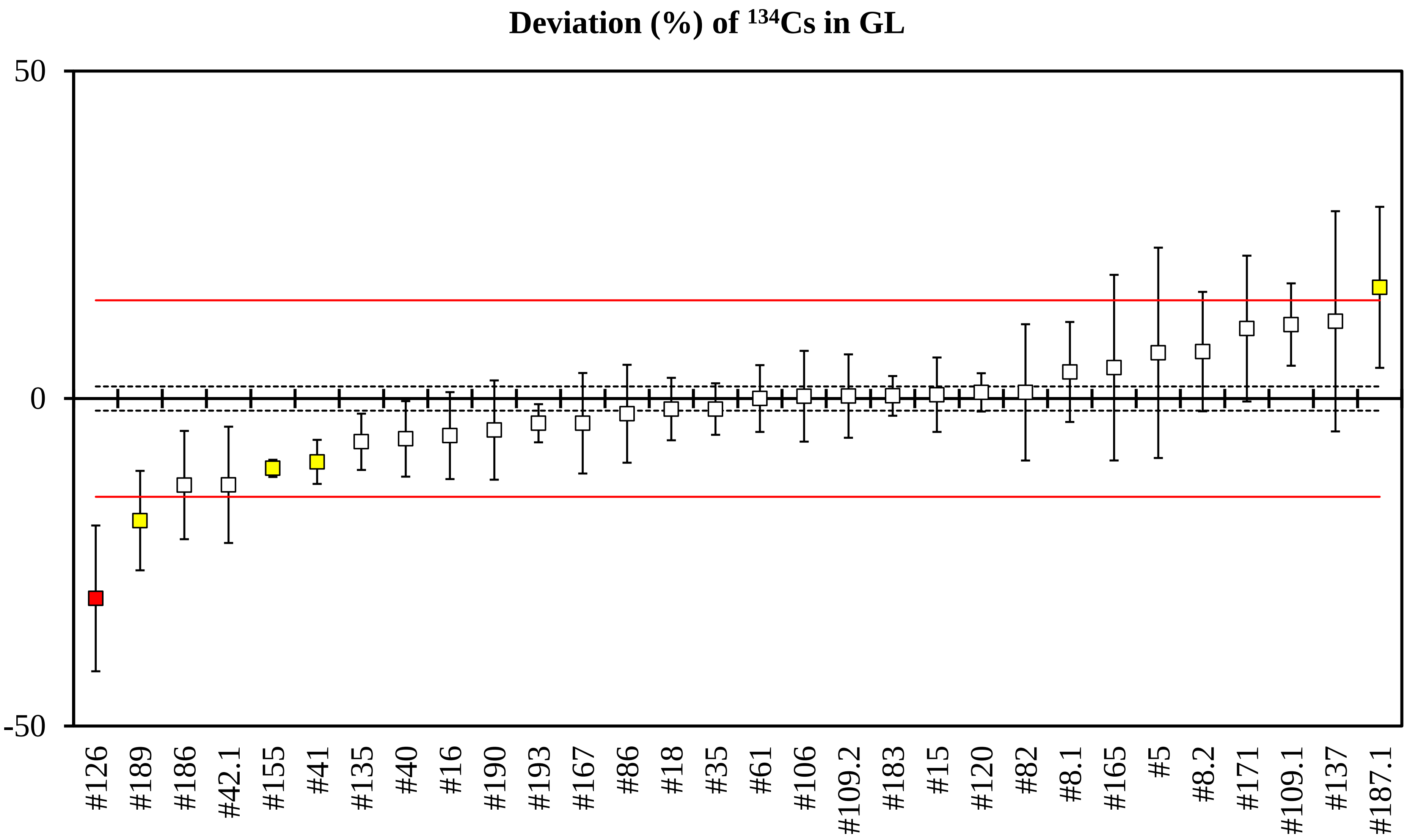
8. GAMMA LOW (GL) DEVIATION PLOTS


Deviation (%) of 134Cs in GL
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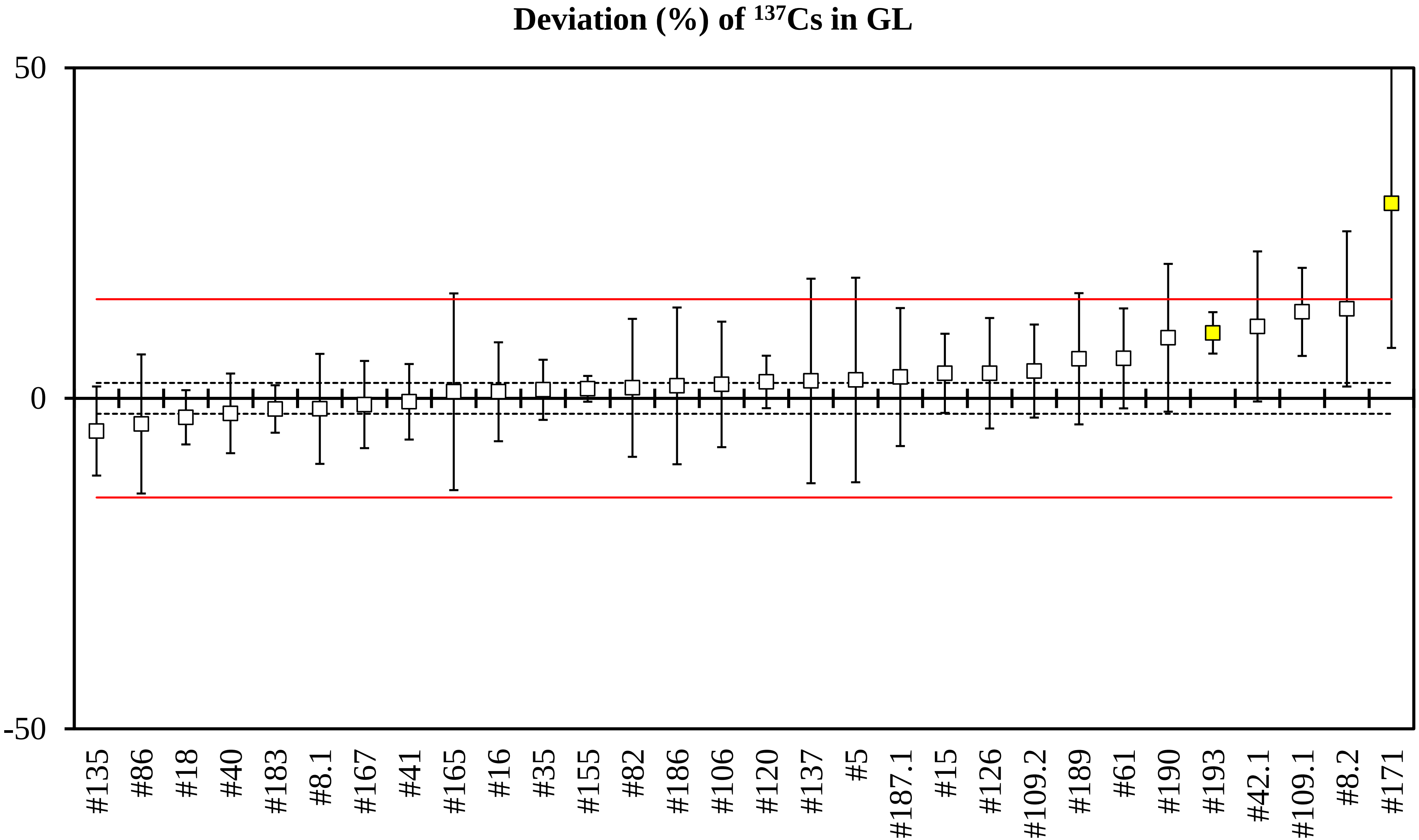
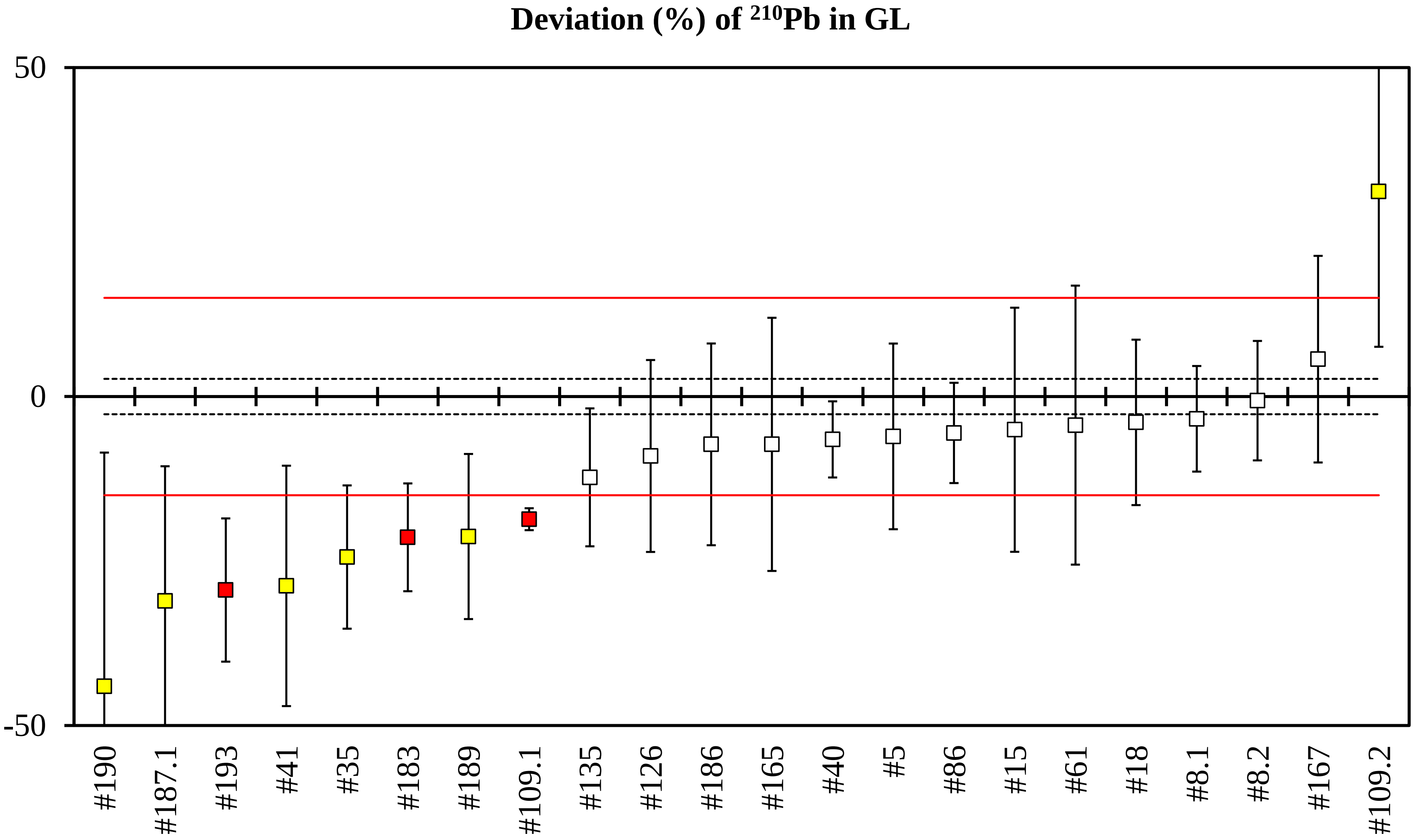
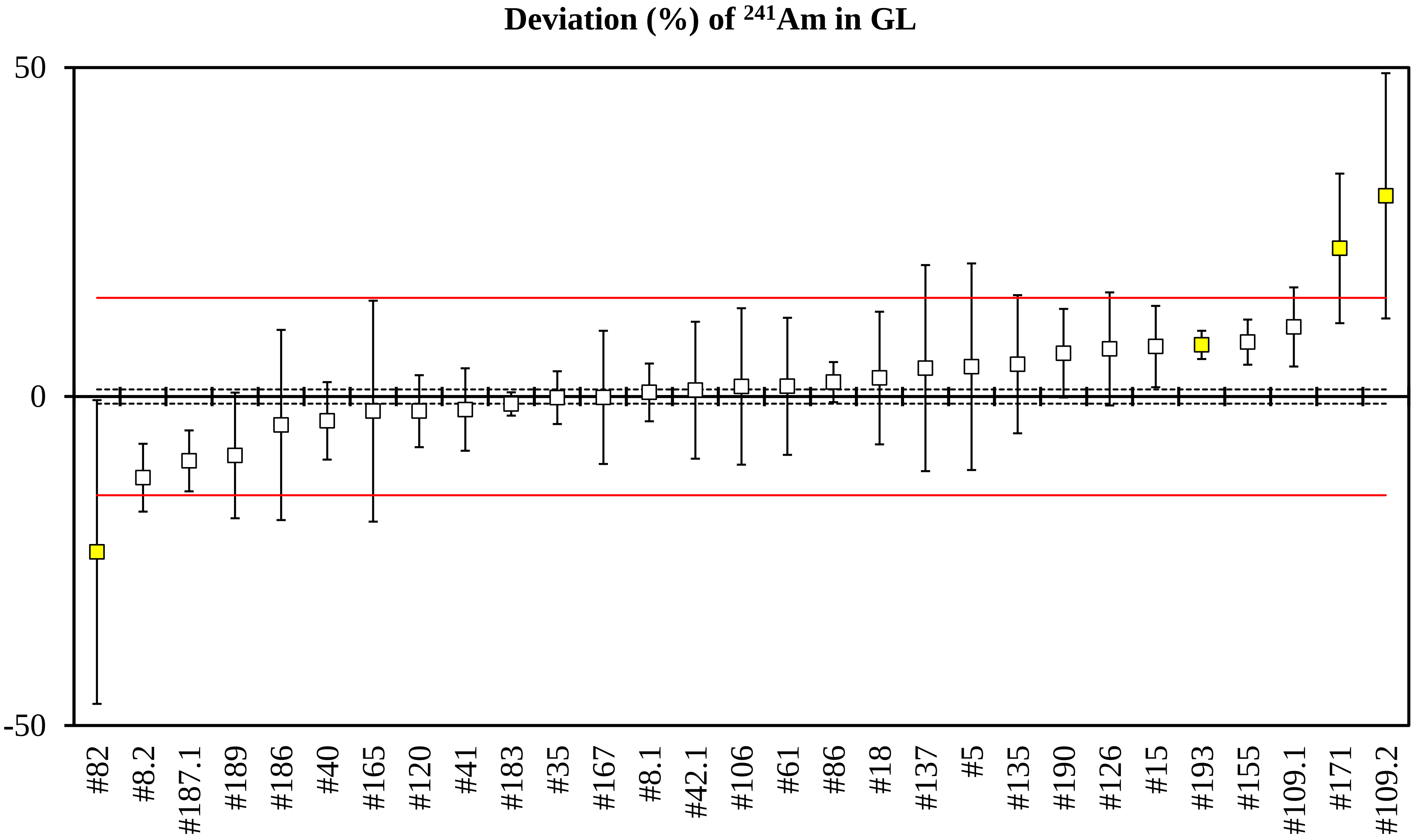
#137
#187.1


Deviation (%) of 137Cs in GL
50
0
-50
#135
#86
#18
#40
#183
#8.1
#167
#41
#165
#16
#35
#155
#82
#186
#106
#120
#137
#5
#187.1
#15
#126
#109.2
#189
#61
#190
#193
#42.1
#109.1
#8.2
#171


Deviation (%) of 210Pb in GL
50
0
-50
#190
#187.1
#193
#41
#35
#183
#189
#109.1
#135
#126
#186
#165
#40
#5
#86
#15
#61
#18
#8.1
#8.2
#167
#109.2

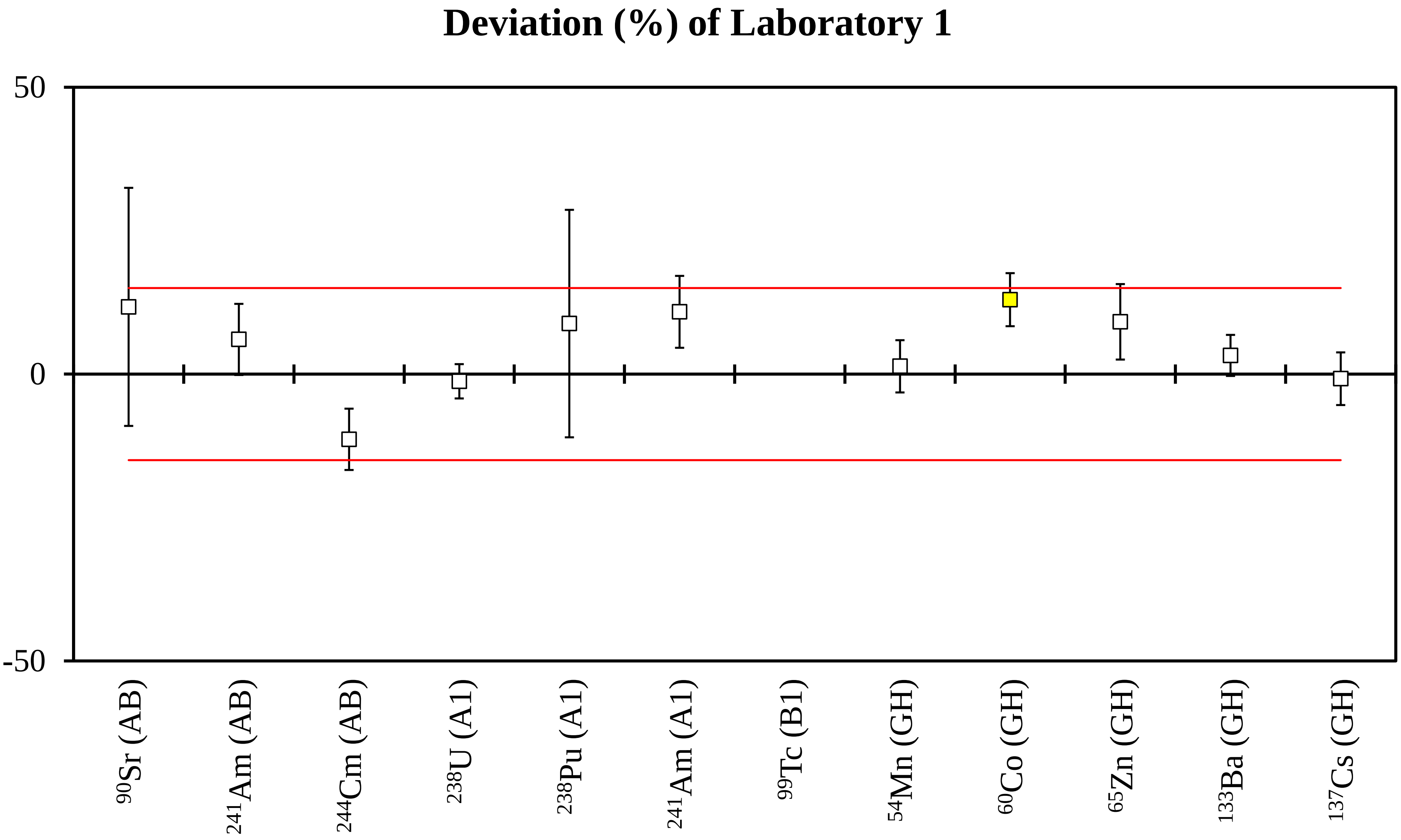


Deviation (%) of 241Am in GL
50
0
-50
#82
#8.2
#187.1
#189
#186
#40
#165
#120
#41
#183
#35
#167
#8.1
#42.1
#106
#61
#86
#18
#137
#5
#135
#190
#126
#15
#193
#155
#109.1
#171
#109.2

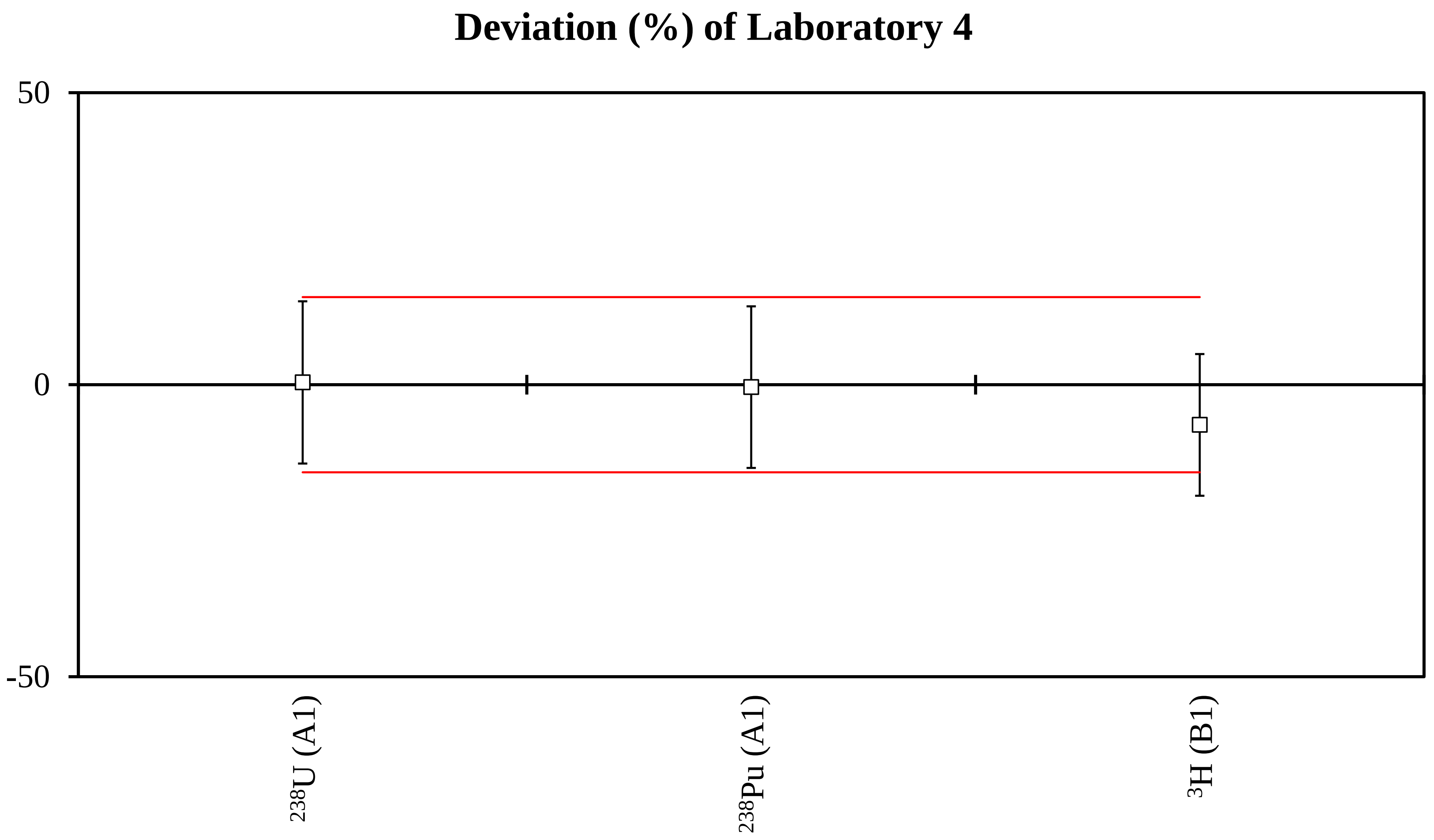
9. DEVIATION PLOTS AND TABULATED RESULTS ARRANGED BY LABORATORY NUMBER

NOTE:

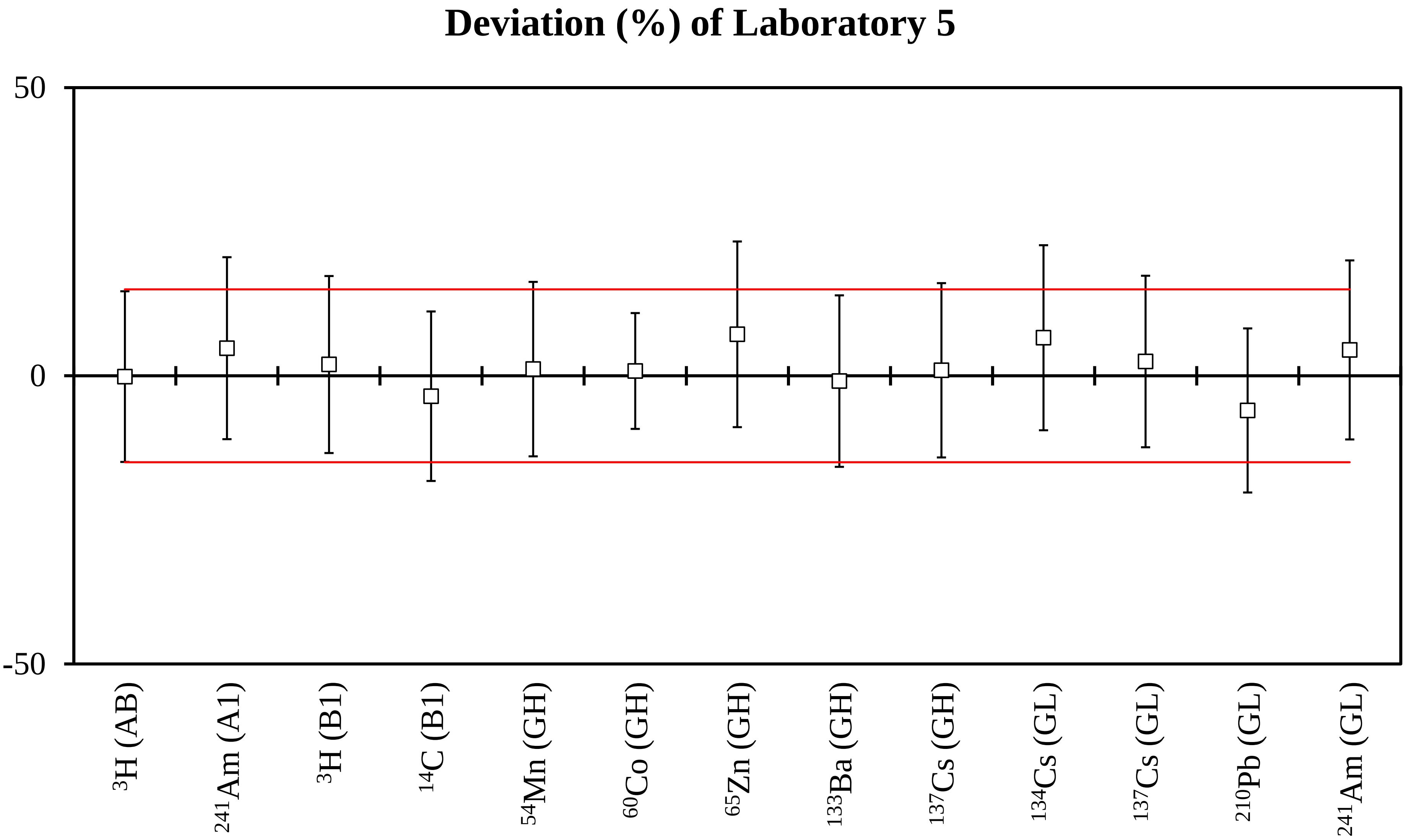
1. Data are quoted rounded, at $k = 1$ (standard uncertainty). Data analysis was carried out on data as reported (i.e. before rounding). Uncertainties have been rounded to two significant figures where more precision has been provided by the participant.
2. Units of the Assigned Values and the reported 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
90Sr (AB)
241Am (AB)
244Cm (AB)
238U (A1)
238Pu (A1)
241Am (A1)
99Tc (B1)
54Mn (GH)
60Co (GH)
65Zn (GH)
133Ba (GH)
137Cs (GH)

Radionuclide	Laboratory 1	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{90}Sr (AB)	7.0 ± 1.3	6.266 ± 0.016	11.7	0.56	2.01
^{241}Am (AB)	8.23 ± 0.48	7.761 ± 0.031	6.0	0.98	1.04
^{244}Cm (AB)	4.48 ± 0.27	5.0547 ± 0.0073	−11.4	−2.13	−1.95
^{238}U (A1)	4.80 ± 0.12	4.861 ± 0.083	−1.3	−0.42	−0.22
^{238}Pu (A1)	2.36 ± 0.43	2.1690 ± 0.0054	8.8	0.44	1.51
^{241}Am (A1)	17.56 ± 0.99	15.841 ± 0.067	10.9	1.73	1.86
^{99}Tc (B1)	0.824 ± 0.024	0.2076 ± 0.0025	296.9	25.55	50.99
^{54}Mn (GH)	5.16 ± 0.23	5.091 ± 0.029	1.4	0.30	0.23
^{60}Co (GH)	2.70 ± 0.11	2.3900 ± 0.0095	13.0	2.81	2.23
^{65}Zn (GH)	2.85 ± 0.17	2.612 ± 0.023	9.1	1.39	1.56
^{133}Ba (GH)	29.18 ± 0.99	28.26 ± 0.20	3.3	0.91	0.56
^{137}Cs (GH)	39.4 ± 1.8	39.72 ± 0.29	−0.8	−0.18	−0.14

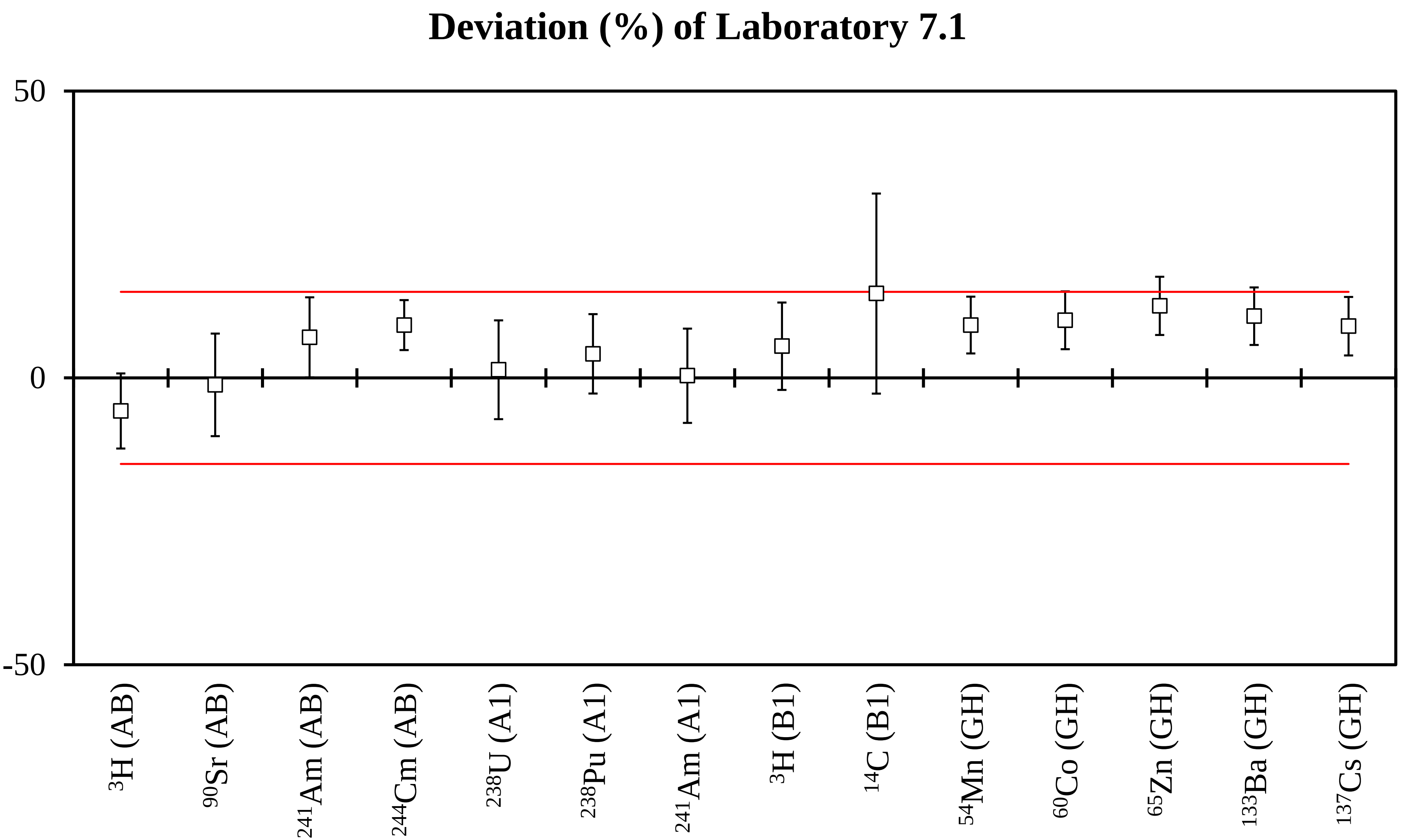

Deviation (%) of Laboratory 4
50
0
-50
238U (A1)
238Pu (A1)
3H (B1)

Radionuclide	Laboratory 4	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{238}U (A1)	4.88 ± 0.67	4.861 ± 0.083	0.4	0.03	0.07
^{238}Pu (A1)	2.16 ± 0.30	2.1690 ± 0.0054	−0.4	−0.03	−0.07
^{3}H (B1)	0.548 ± 0.071	0.5885 ± 0.0081	−6.9	−0.57	−1.18

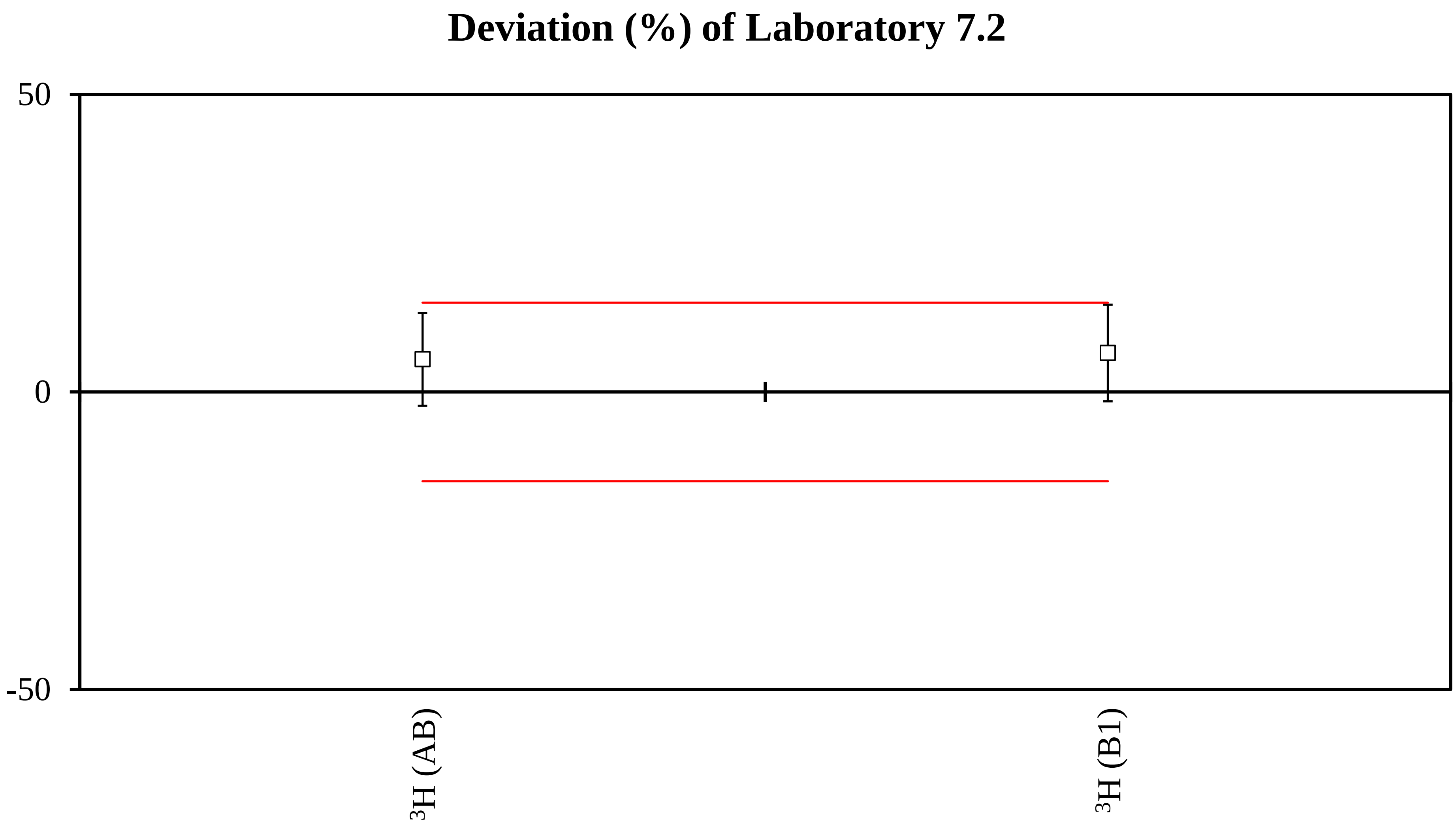


Deviation (%) of Laboratory 5
50
0
-50
3H (AB)
241Am (A1)
3H (B1)
14C (B1)
54Mn (GH)
60Co (GH)
65Zn (GH)
133Ba (GH)
137Cs (GH)
134Cs (GL)
137Cs (GL)
210Pb (GL)
241Am (GL)

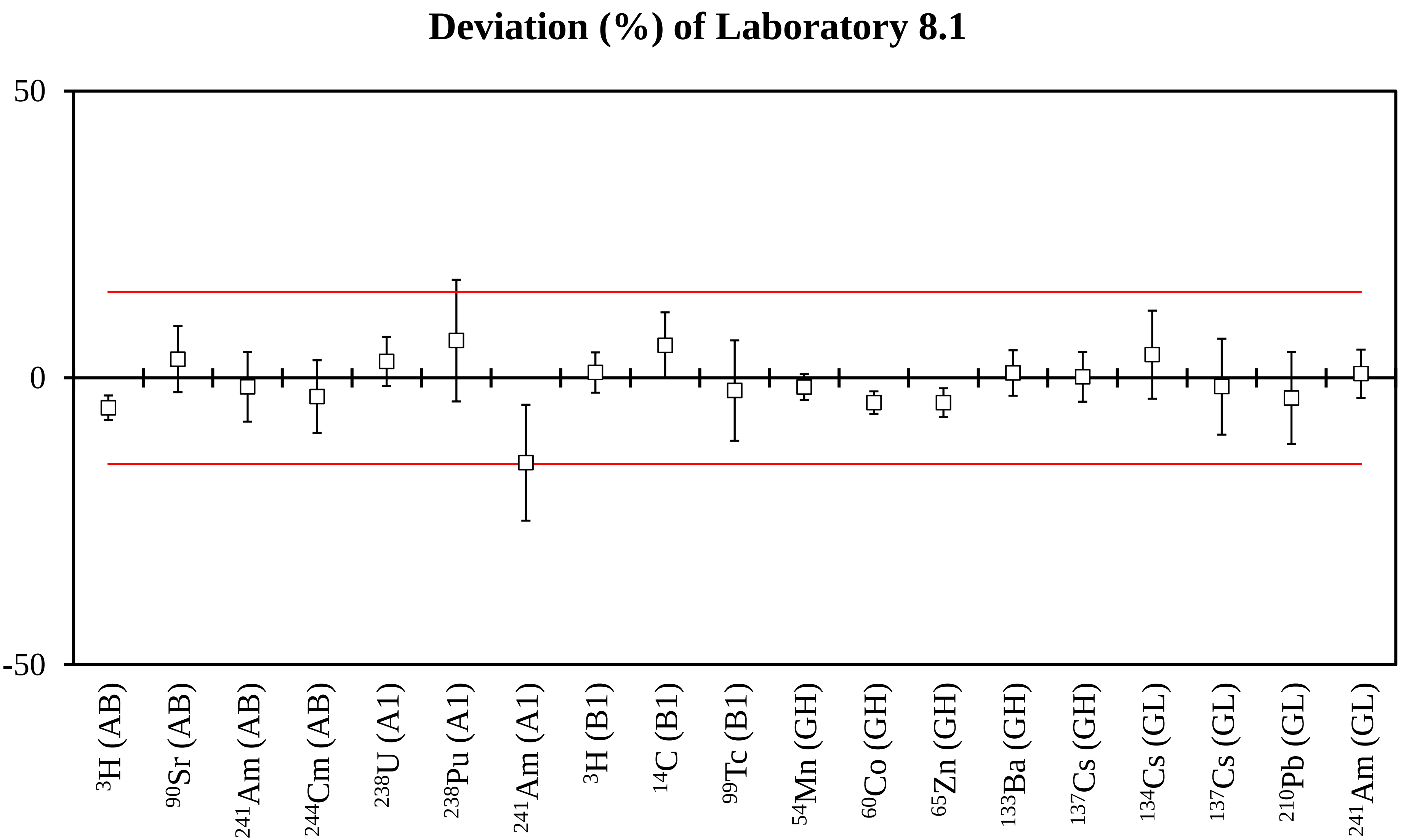
Radionuclide	Laboratory 5	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	14.2 ± 2.1	14.22 ± 0.15	−0.1	−0.01	−0.02
^{241}Am (A1)	16.6 ± 2.5	15.841 ± 0.067	4.8	0.30	0.82
^{3}H (B1)	0.60 ± 0.09	0.5885 ± 0.0081	2.0	0.13	0.34
^{14}C (B1)	0.46 ± 0.07	0.4769 ± 0.0044	−3.5	−0.24	−0.61
^{54}Mn (GH)	5.15 ± 0.77	5.091 ± 0.029	1.2	0.08	0.20
^{60}Co (GH)	2.41 ± 0.24	2.3900 ± 0.0095	0.8	0.08	0.14
^{65}Zn (GH)	2.80 ± 0.42	2.612 ± 0.023	7.2	0.45	1.24
^{133}Ba (GH)	28.0 ± 4.2	28.26 ± 0.20	−0.9	−0.06	−0.16
^{137}Cs (GH)	40.1 ± 6.0	39.72 ± 0.29	1.0	0.06	0.16
^{134}Cs (GL)	11.3 ± 1.7	10.600 ± 0.076	6.6	0.41	1.13
^{137}Cs (GL)	6.9 ± 1.0	6.733 ± 0.061	2.5	0.17	0.43
^{210}Pb (GL)	22.5 ± 3.4	23.94 ± 0.25	−6.0	−0.42	−1.03
^{241}Am (GL)	24.9 ± 3.7	23.83 ± 0.10	4.5	0.29	0.77


Deviation (%) of Laboratory 7.1
50
0
-50
3H (AB)
90Sr (AB)
241Am (AB)
244Cm (AB)
238U (A1)
238Pu (A1)
241Am (A1)
3H (B1)
14C (B1)
54Mn (GH)
60Co (GH)
65Zn (GH)
133Ba (GH)
137Cs (GH)

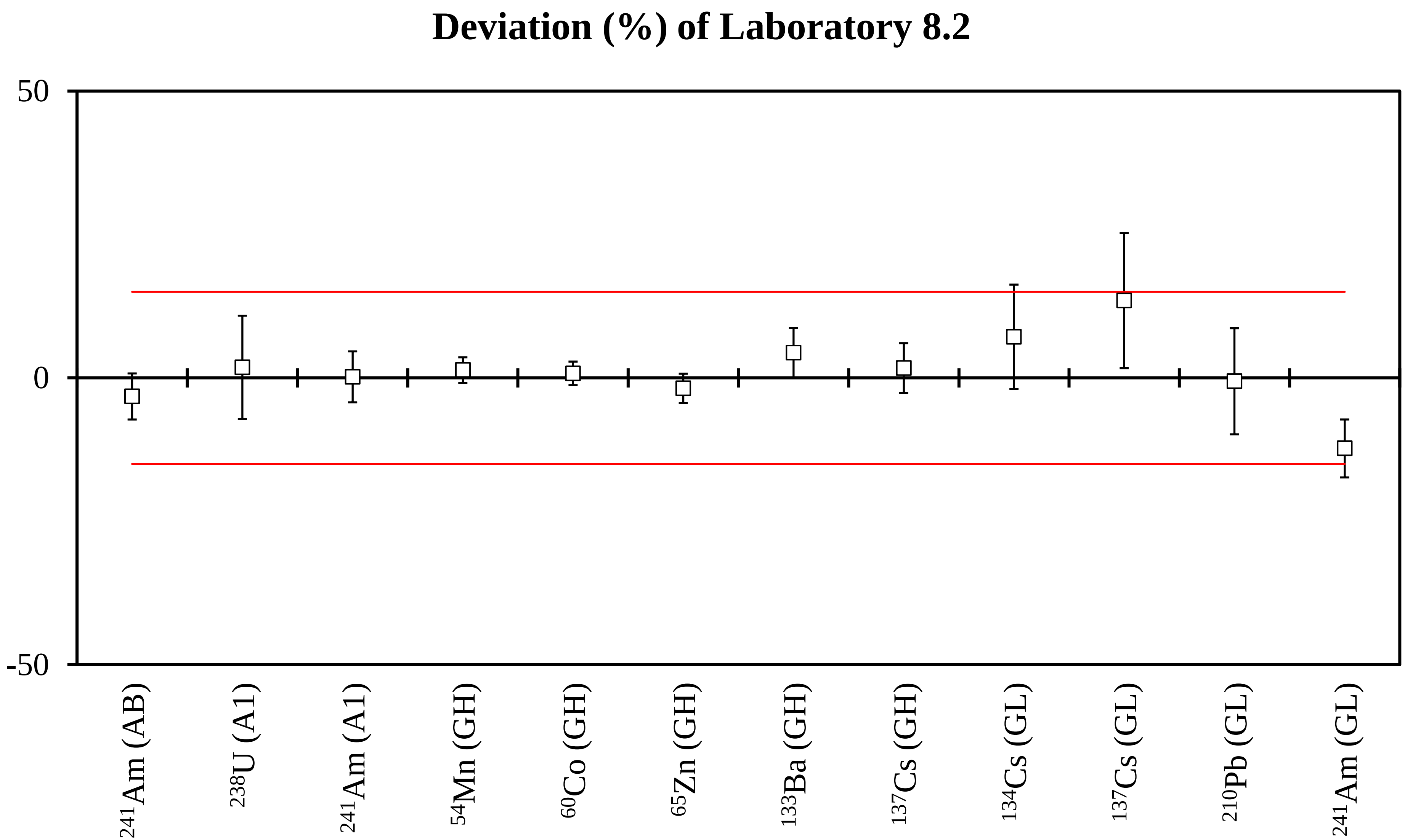
Radionuclide	Laboratory 7.1	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	13.40 ± 0.92	14.22 ± 0.15	−5.8	−0.88	−0.99
^{90}Sr (AB)	6.19 ± 0.56	6.266 ± 0.016	−1.2	−0.14	−0.21
^{241}Am (AB)	8.31 ± 0.54	7.761 ± 0.031	7.1	1.01	1.21
^{244}Cm (AB)	5.52 ± 0.22	5.0547 ± 0.0073	9.2	2.11	1.58
^{238}U (A1)	4.93 ± 0.41	4.861 ± 0.083	1.4	0.16	0.24
^{238}Pu (A1)	2.26 ± 0.15	2.1690 ± 0.0054	4.2	0.61	0.72
^{241}Am (A1)	15.9 ± 1.3	15.841 ± 0.067	0.4	0.05	0.06
^{3}H (B1)	0.621 ± 0.044	0.5885 ± 0.0081	5.5	0.73	0.95
^{14}C (B1)	0.547 ± 0.083	0.4769 ± 0.0044	14.7	0.84	2.52
^{54}Mn (GH)	5.56 ± 0.25	5.091 ± 0.029	9.2	1.86	1.58
^{60}Co (GH)	2.63 ± 0.12	2.3900 ± 0.0095	10.0	1.99	1.72
^{65}Zn (GH)	2.94 ± 0.13	2.612 ± 0.023	12.6	2.48	2.16
^{133}Ba (GH)	31.3 ± 1.4	28.26 ± 0.20	10.8	2.15	1.85
^{137}Cs (GH)	43.3 ± 2.0	39.72 ± 0.29	9.0	1.77	1.55


Deviation (%) of Laboratory 7.2
50
0
-50
3H (AB)
3H (B1)

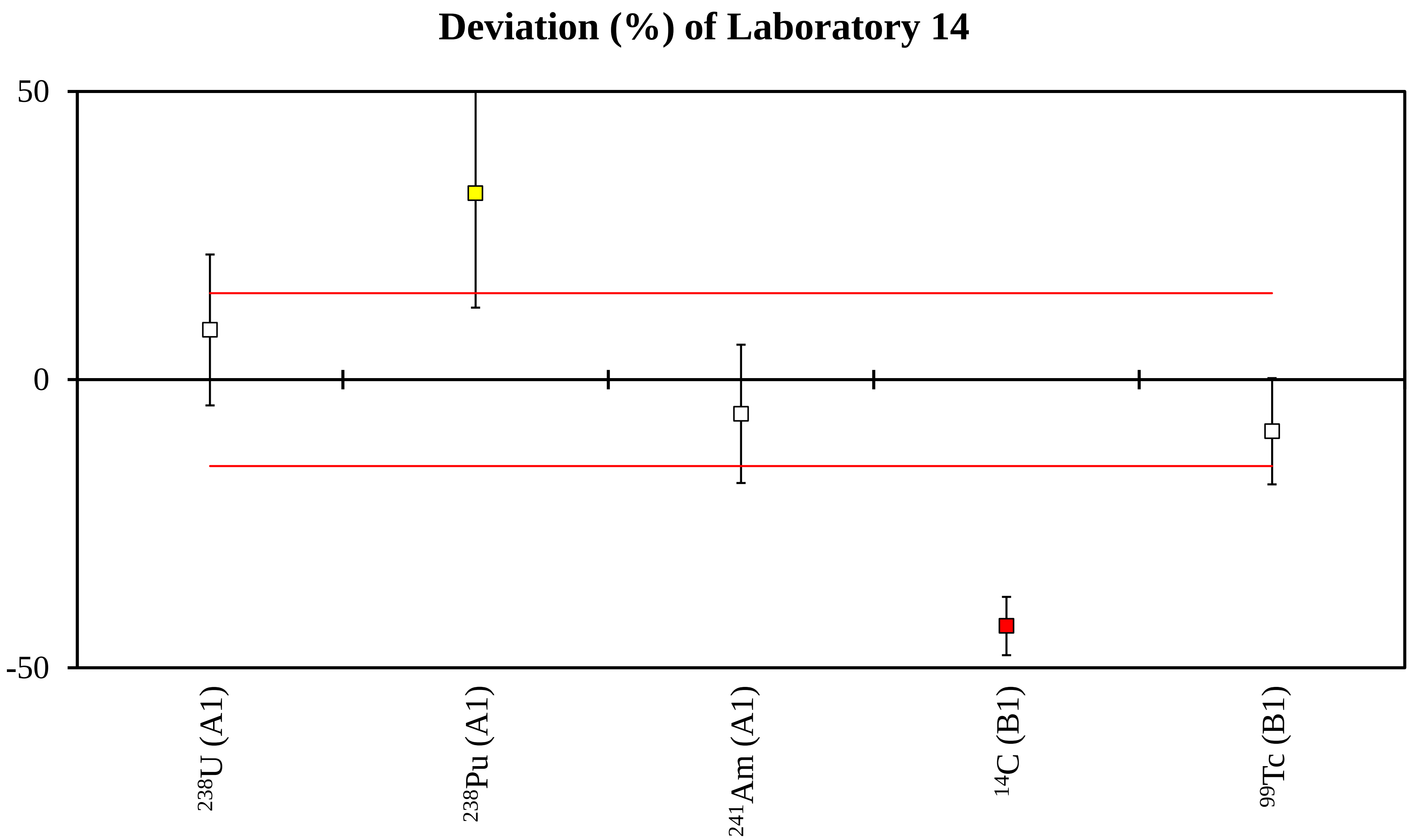
Radionuclide	Laboratory 7.2	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	15.0 ± 1.1	14.22 ± 0.15	5.5	0.70	0.94
^{3}H (B1)	0.627 ± 0.047	0.5885 ± 0.0081	6.5	0.81	1.12


Deviation (%) of Laboratory 8.1
50
0
-50
3H (AB)
90Sr (AB)
241Am (AB)
244Cm (AB)
238U (A1)
238Pu (A1)
241Am (A1)
3H (B1)
14C (B1)
99Tc (B1)
54Mn (GH)
60Co (GH)
65Zn (GH)
133Ba (GH)
137Cs (GH)
134Cs (GL)
137Cs (GL)
210Pb (GL)
241Am (GL)

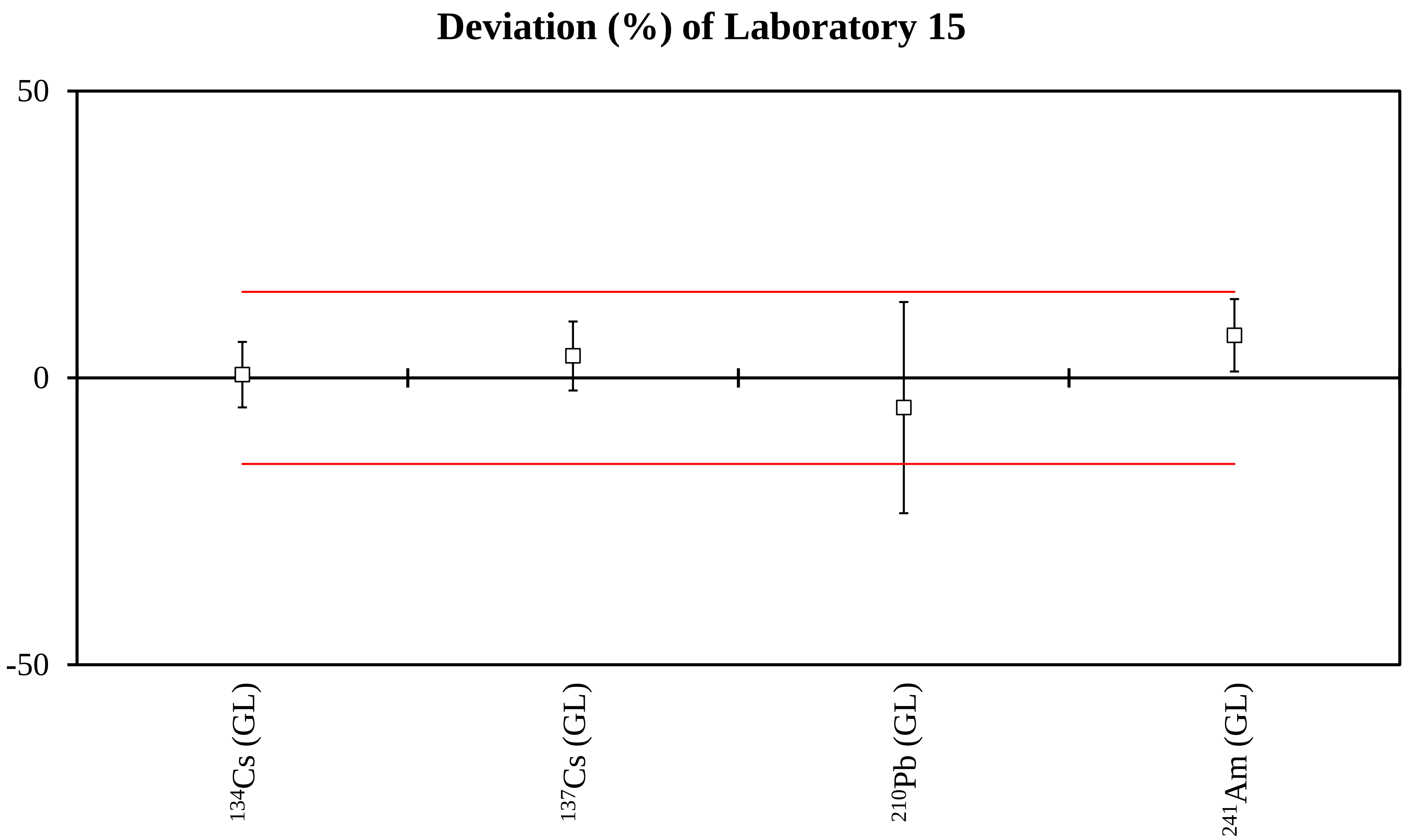
Radionuclide	Laboratory 8.1	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	13.48 ± 0.27	14.22 ± 0.15	−5.2	−2.40	−0.89
^{90}Sr (AB)	6.47 ± 0.36	6.266 ± 0.016	3.3	0.57	0.56
^{241}Am (AB)	7.64 ± 0.47	7.761 ± 0.031	−1.6	−0.26	−0.27
^{244}Cm (AB)	4.89 ± 0.32	5.0547 ± 0.0073	−3.3	−0.51	−0.56
^{238}U (A1)	5.00 ± 0.19	4.861 ± 0.083	2.9	0.67	0.49
^{238}Pu (A1)	2.31 ± 0.23	2.1690 ± 0.0054	6.5	0.61	1.12
^{241}Am (A1)	13.5 ± 1.6	15.841 ± 0.067	−14.8	−1.46	−2.54
^{3}H (B1)	0.594 ± 0.019	0.5885 ± 0.0081	0.9	0.27	0.16
^{14}C (B1)	0.504 ± 0.027	0.4769 ± 0.0044	5.7	0.99	0.98
^{99}Tc (B1)	0.203 ± 0.018	0.2076 ± 0.0025	−2.2	−0.25	−0.38
^{54}Mn (GH)	5.01 ± 0.11	5.091 ± 0.029	−1.6	−0.71	−0.27
^{60}Co (GH)	2.287 ± 0.046	2.3900 ± 0.0095	−4.3	−2.19	−0.74
^{65}Zn (GH)	2.499 ± 0.062	2.612 ± 0.023	−4.3	−1.71	−0.74
^{133}Ba (GH)	28.5 ± 1.1	28.26 ± 0.20	0.8	0.21	0.15
^{137}Cs (GH)	39.8 ± 1.7	39.72 ± 0.29	0.2	0.05	0.03
^{134}Cs (GL)	11.03 ± 0.81	10.600 ± 0.076	4.1	0.53	0.70
^{137}Cs (GL)	6.63 ± 0.56	6.733 ± 0.061	−1.5	−0.18	−0.26
^{210}Pb (GL)	23.1 ± 1.9	23.94 ± 0.25	−3.5	−0.44	−0.60
^{241}Am (GL)	24.0 ± 1.0	23.83 ± 0.10	0.7	0.17	0.12


Deviation (%) of Laboratory 8.2
50
0
-50
241Am (AB)
238U (A1)
241Am (A1)
54Mn (GH)
60Co (GH)
65Zn (GH)
133Ba (GH)
137Cs (GH)
134Cs (GL)
137Cs (GL)
210Pb (GL)
241Am (GL)

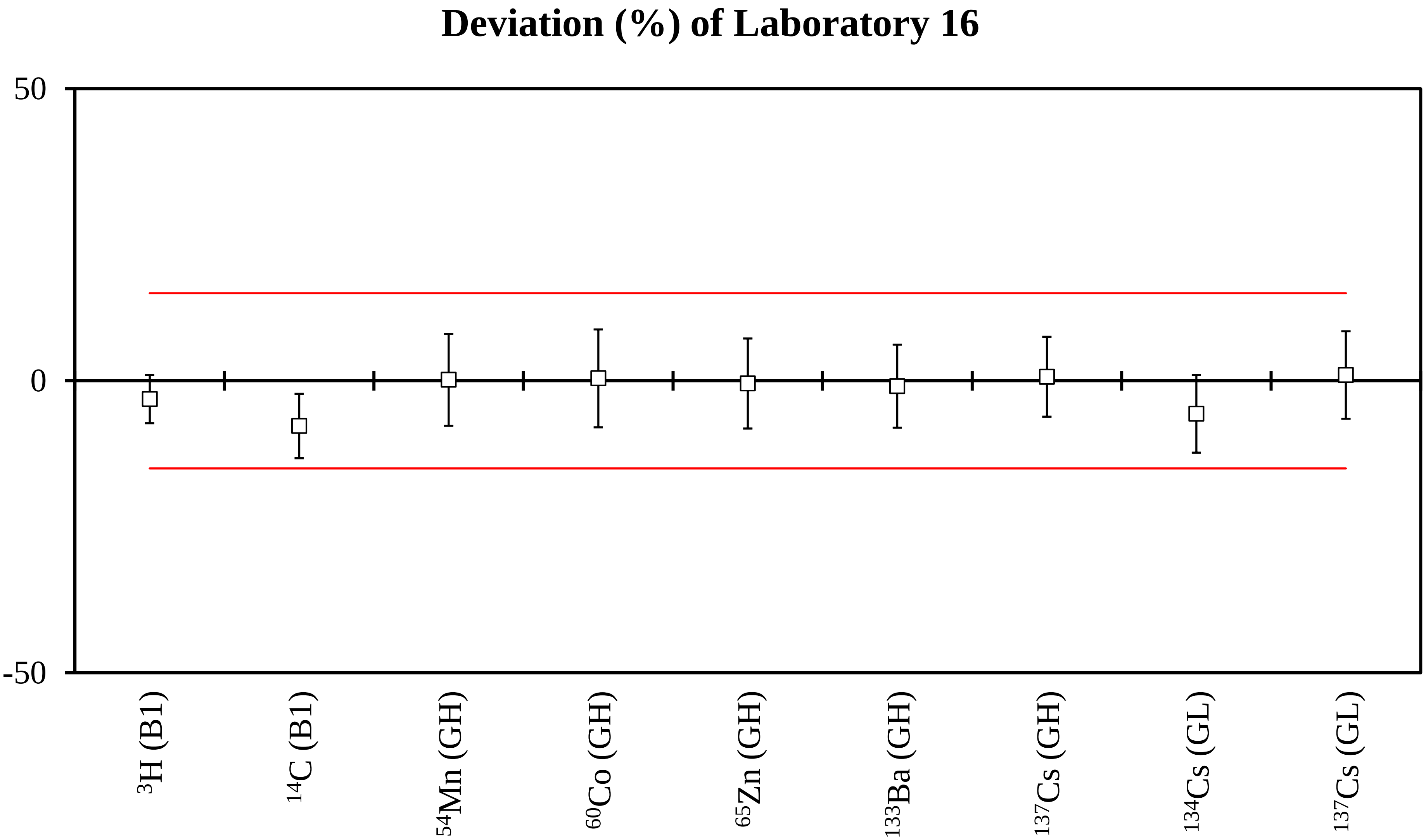
Radionuclide	Laboratory 8.2	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{241}Am (AB)	7.51 ± 0.31	7.761 ± 0.031	−3.2	−0.81	−0.56
^{238}U (A1)	4.95 ± 0.43	4.861 ± 0.083	1.8	0.20	0.31
^{241}Am (A1)	15.87 ± 0.70	15.841 ± 0.067	0.2	0.04	0.03
^{54}Mn (GH)	5.16 ± 0.11	5.091 ± 0.029	1.4	0.61	0.23
^{60}Co (GH)	2.409 ± 0.048	2.3900 ± 0.0095	0.8	0.39	0.14
^{65}Zn (GH)	2.564 ± 0.063	2.612 ± 0.023	−1.8	−0.72	−0.32
^{133}Ba (GH)	29.5 ± 1.2	28.26 ± 0.20	4.4	1.02	0.75
^{137}Cs (GH)	40.4 ± 1.7	39.72 ± 0.29	1.7	0.39	0.29
^{134}Cs (GL)	11.36 ± 0.96	10.600 ± 0.076	7.2	0.79	1.23
^{137}Cs (GL)	7.64 ± 0.79	6.733 ± 0.061	13.5	1.14	2.31
^{210}Pb (GL)	23.8 ± 2.2	23.94 ± 0.25	−0.6	−0.06	−0.10
^{241}Am (GL)	20.9 ± 1.2	23.83 ± 0.10	−12.3	−2.43	−2.11


Deviation (%) of Laboratory 14
50
0
-50
238U (A1)
238Pu (A1)
241Am (A1)
14C (B1)
99Tc (B1)

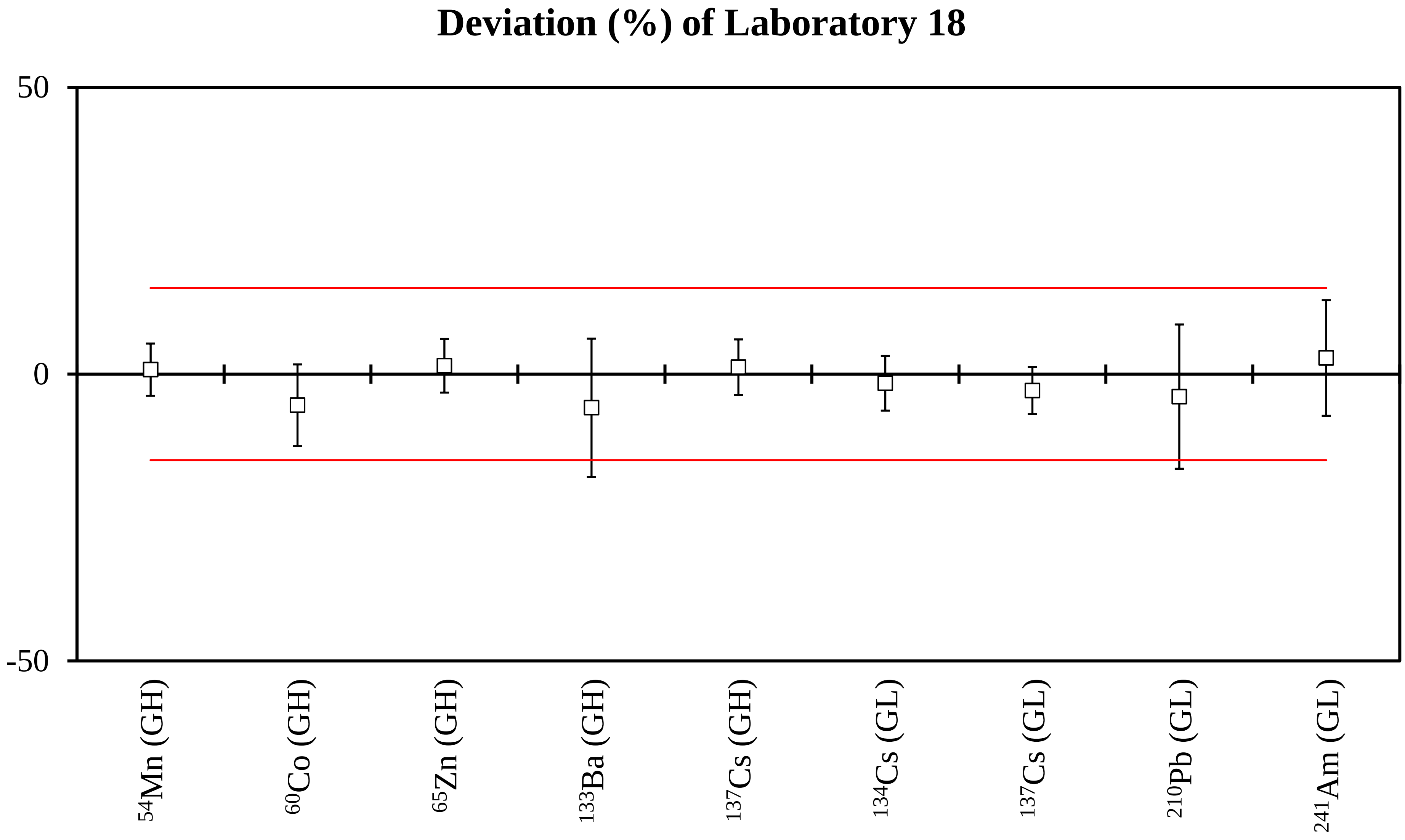
Radionuclide	Laboratory 14	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{238}U (A1)	5.28 ± 0.63	4.861 ± 0.083	8.6	0.66	1.48
^{238}Pu (A1)	2.87 ± 0.43	2.1690 ± 0.0054	32.3	1.63	5.55
^{241}Am (A1)	14.9 ± 1.9	15.841 ± 0.067	−5.9	−0.49	−1.02
^{14}C (B1)	0.273 ± 0.024	0.4769 ± 0.0044	−42.8	−8.36	−7.34
^{99}Tc (B1)	0.189 ± 0.019	0.2076 ± 0.0025	−9.0	−0.97	−1.54


Deviation (%) of Laboratory 15
50
0
-50
^{134}Cs (GL)
^{137}Cs (GL)
^{210}Pb (GL)
^{241}Am (GL)

Radionuclide	Laboratory 15	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{134}Cs (GL)	10.66 ± 0.60	10.600 ± 0.076	0.6	0.10	0.10
^{137}Cs (GL)	6.99 ± 0.40	6.733 ± 0.061	3.8	0.64	0.66
^{210}Pb (GL)	22.7 ± 4.4	23.94 ± 0.25	−5.2	−0.28	−0.89
^{241}Am (GL)	25.6 ± 1.5	23.83 ± 0.10	7.4	1.18	1.28

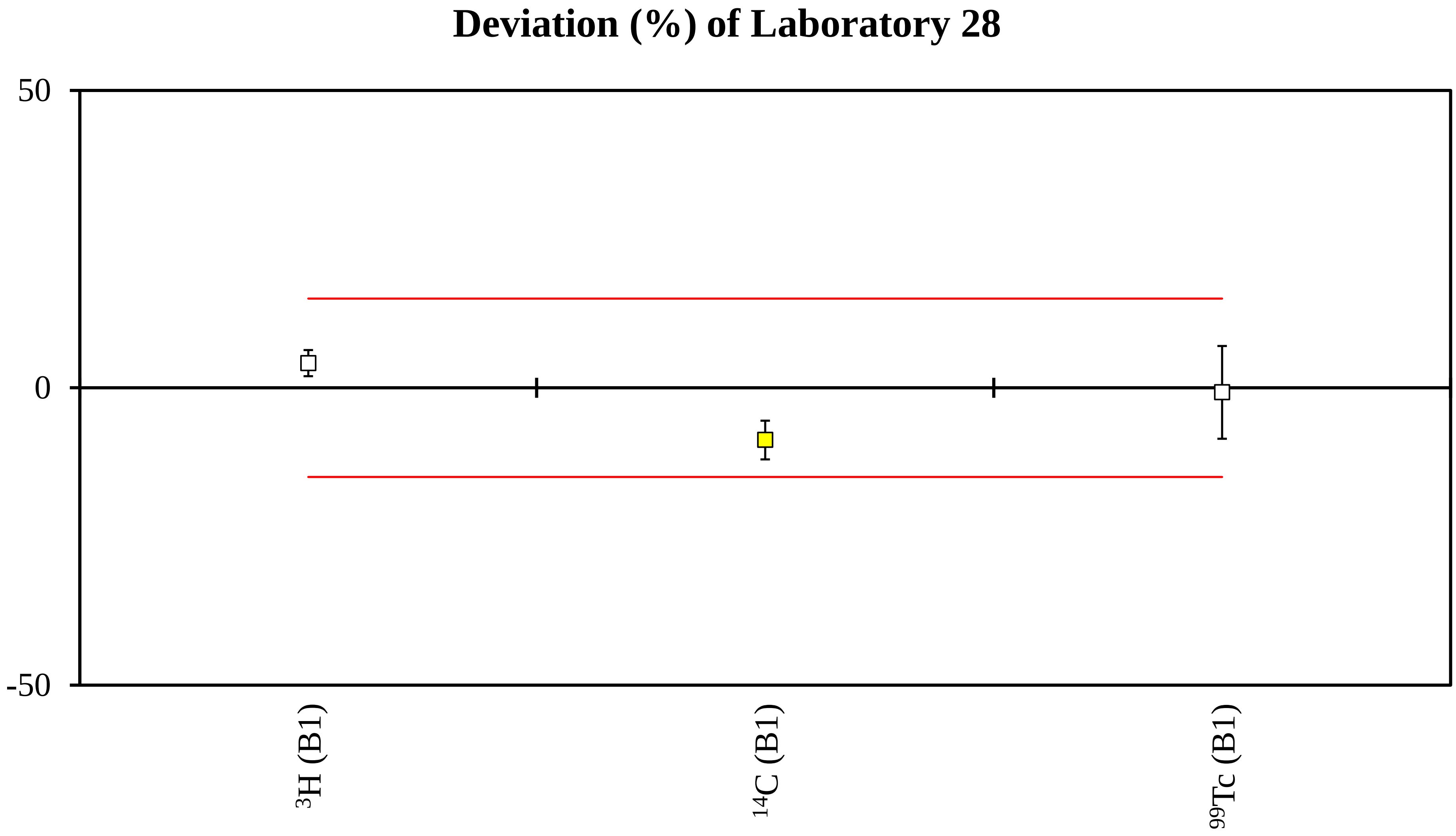

Deviation (%) of Laboratory 16
50
0
-50
3H (B1)
14C (B1)
54Mn (GH)
60Co (GH)
65Zn (GH)
133Ba (GH)
137Cs (GH)
134Cs (GL)
137Cs (GL)

Radionuclide	Laboratory 16	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (B1)	0.570 ± 0.023	0.5885 ± 0.0081	−3.1	−0.76	−0.54
^{14}C (B1)	0.440 ± 0.026	0.4769 ± 0.0044	−7.7	−1.40	−1.33
^{54}Mn (GH)	5.10 ± 0.40	5.091 ± 0.029	0.2	0.02	0.03
^{60}Co (GH)	2.40 ± 0.20	2.3900 ± 0.0095	0.4	0.05	0.07
^{65}Zn (GH)	2.60 ± 0.20	2.612 ± 0.023	−0.5	−0.06	−0.08
^{133}Ba (GH)	28.0 ± 2.0	28.26 ± 0.20	−0.9	−0.13	−0.16
^{137}Cs (GH)	40.0 ± 2.7	39.72 ± 0.29	0.7	0.10	0.12
^{134}Cs (GL)	10.0 ± 0.7	10.600 ± 0.076	−5.7	−0.85	−0.97
^{137}Cs (GL)	6.80 ± 0.50	6.733 ± 0.061	1.0	0.13	0.17

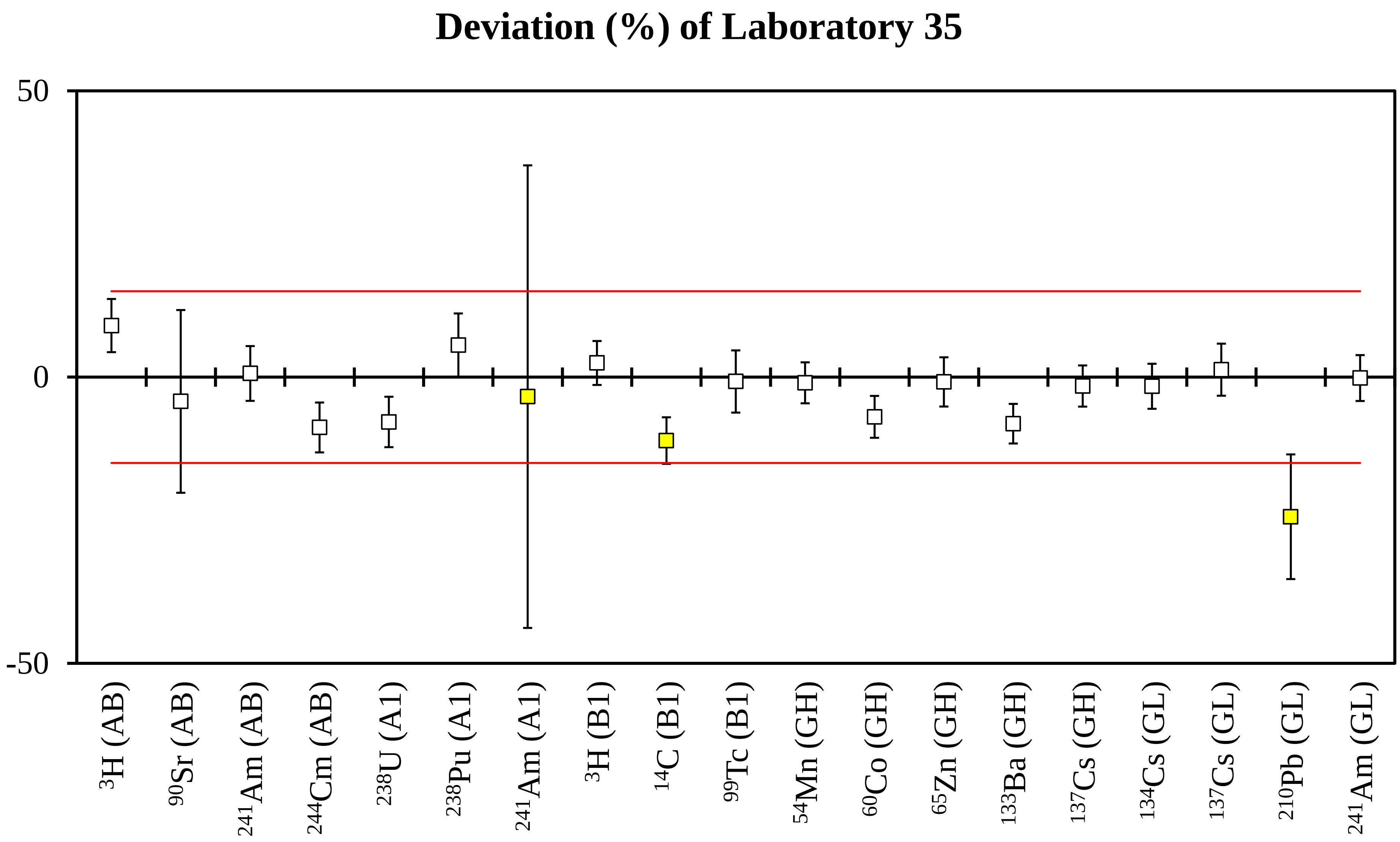


Deviation (%) of Laboratory 18
50
0
-50
54Mn (GH)
60Co (GH)
65Zn (GH)
133Ba (GH)
137Cs (GH)
134Cs (GL)
137Cs (GL)
210Pb (GL)
241Am (GL)

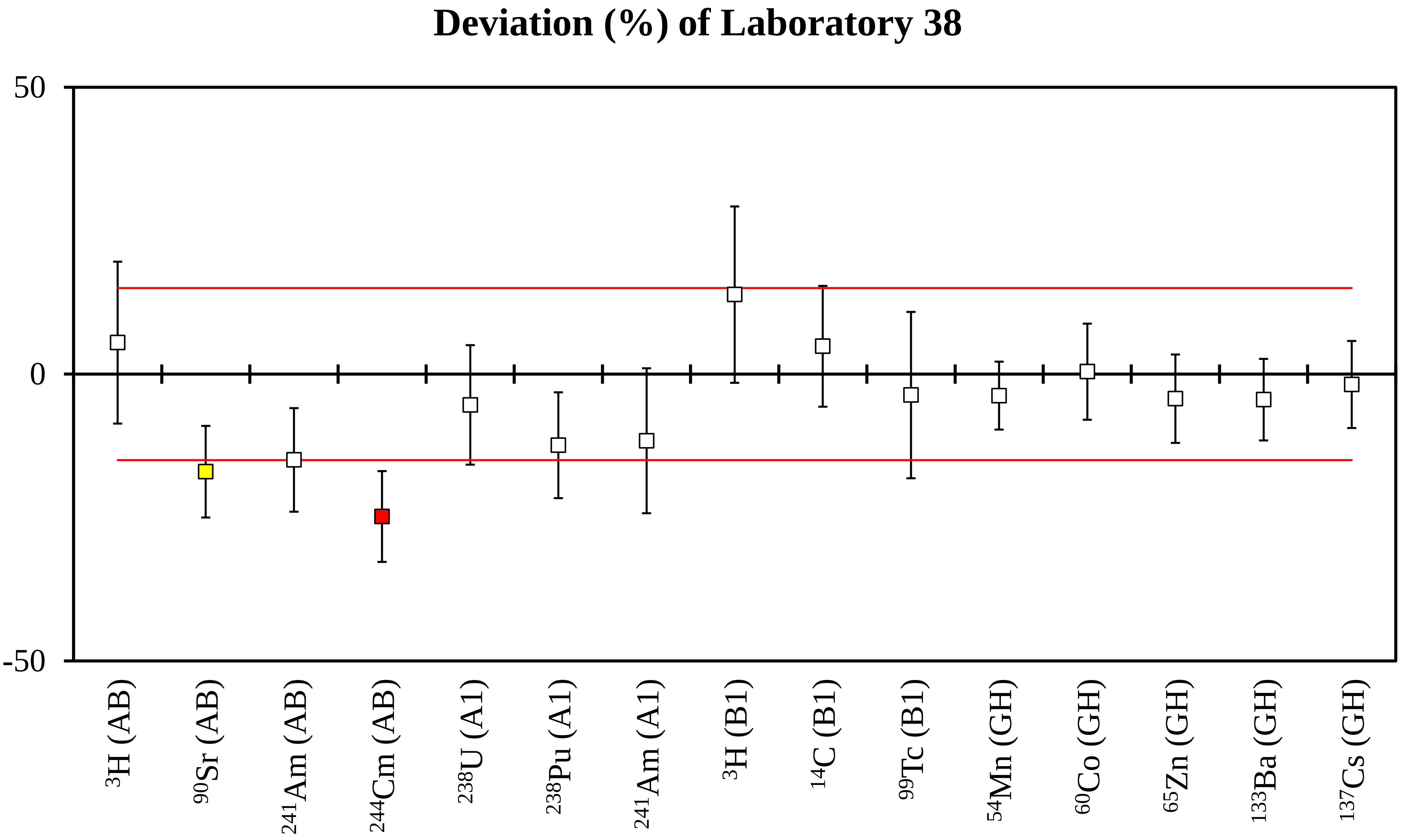
Radionuclide	Laboratory 18	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{54}Mn (GH)	5.13 ± 0.23	5.091 ± 0.029	0.8	0.17	0.13
^{60}Co (GH)	2.26 ± 0.17	2.3900 ± 0.0095	−5.4	−0.76	−0.93
^{65}Zn (GH)	2.65 ± 0.12	2.612 ± 0.023	1.5	0.31	0.25
^{133}Ba (GH)	26.6 ± 3.4	28.26 ± 0.20	−5.9	−0.49	−1.01
^{137}Cs (GH)	40.2 ± 1.9	39.72 ± 0.29	1.2	0.25	0.21
^{134}Cs (GL)	10.43 ± 0.50	10.600 ± 0.076	−1.6	−0.34	−0.28
^{137}Cs (GL)	6.54 ± 0.27	6.733 ± 0.061	−2.9	−0.70	−0.49
^{210}Pb (GL)	23.0 ± 3.0	23.94 ± 0.25	−3.9	−0.31	−0.67
^{241}Am (GL)	24.5 ± 2.4	23.83 ± 0.10	2.8	0.28	0.48


Deviation (%) of Laboratory 28
50
0
-50
3H (B1)
14C (B1)
99Tc (B1)

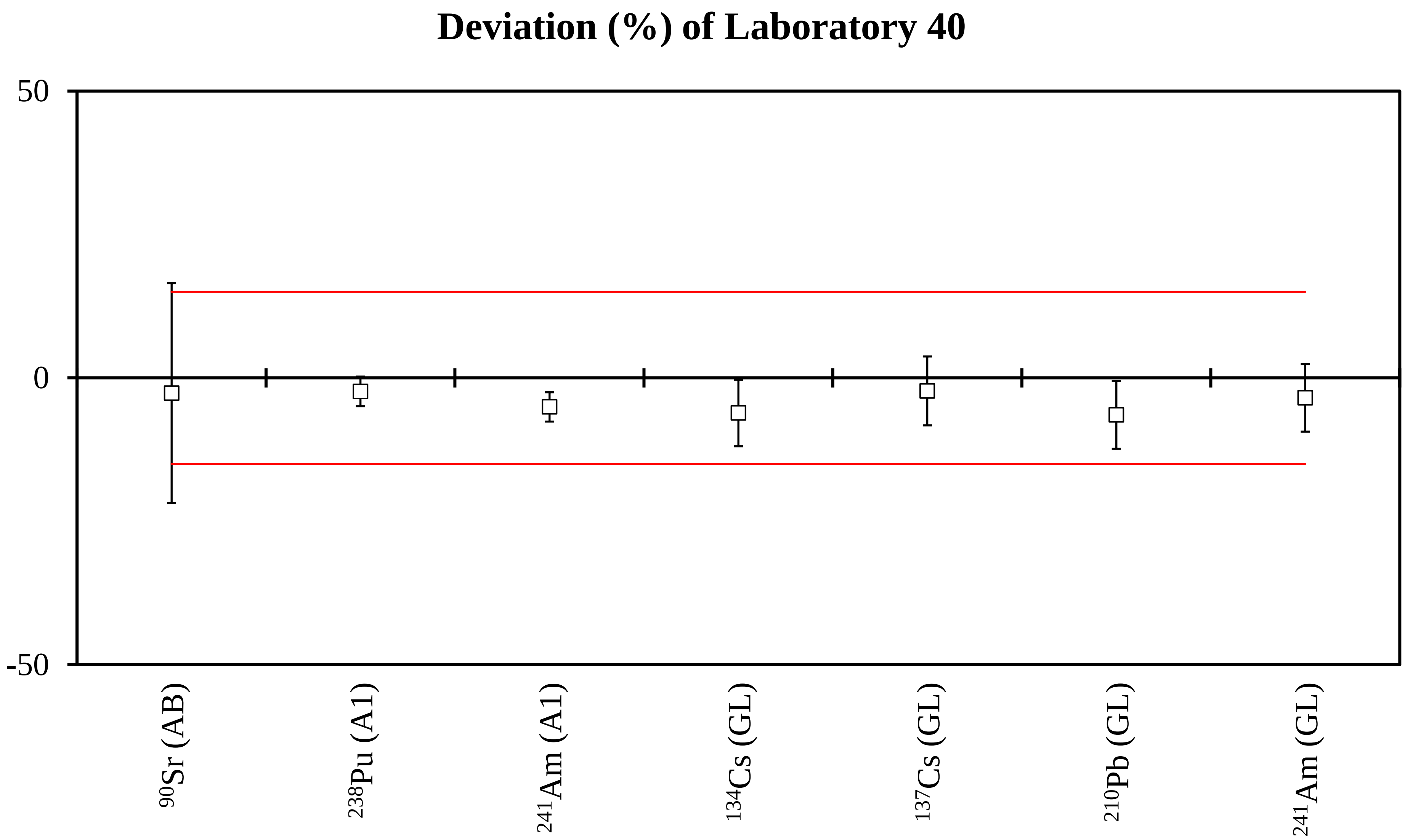
Radionuclide	Laboratory 28	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (B1)	0.6129 ± 0.0098	0.5885 ± 0.0081	4.1	1.92	0.71
^{14}C (B1)	0.435 ± 0.015	0.4769 ± 0.0044	−8.8	−2.68	−1.51
^{99}Tc (B1)	0.206 ± 0.016	0.2076 ± 0.0025	−0.8	−0.10	−0.13


Deviation (%) of Laboratory 35
50
0
-50
3H (AB)
90Sr (AB)
241Am (AB)
244Cm (AB)
238U (A1)
238Pu (A1)
241Am (A1)
3H (B1)
14C (B1)
99Tc (B1)
54Mn (GH)
60Co (GH)
65Zn (GH)
133Ba (GH)
137Cs (GH)
134Cs (GL)
137Cs (GL)
210Pb (GL)
241Am (GL)

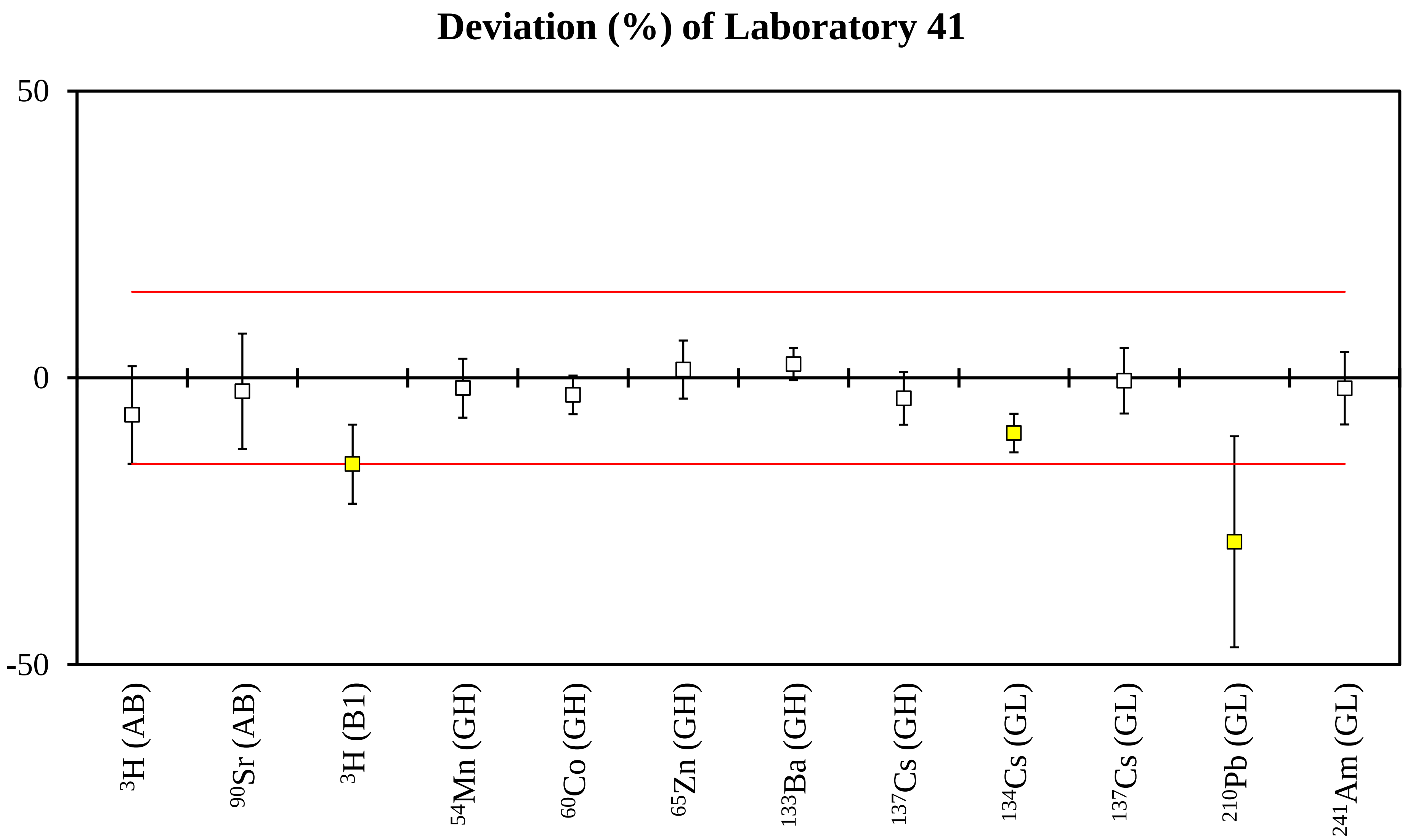
Radionuclide	Laboratory 35	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	15.50 ± 0.64	14.22 ± 0.15	9.0	1.95	1.55
^{90}Sr (AB)	6.0 ± 1.0	6.266 ± 0.016	−4.2	−0.27	−0.73
^{241}Am (AB)	7.81 ± 0.37	7.761 ± 0.031	0.6	0.13	0.11
^{244}Cm (AB)	4.61 ± 0.22	5.0547 ± 0.0073	−8.8	−2.02	−1.51
^{238}U (A1)	4.48 ± 0.20	4.861 ± 0.083	−7.8	−1.76	−1.35
^{238}Pu (A1)	2.29 ± 0.12	2.1690 ± 0.0054	5.6	1.01	0.96
^{241}Am (A1)	15.3 ± 6.4	15.841 ± 0.067	−3.4	−0.08	−0.59
^{3}H (B1)	0.603 ± 0.021	0.5885 ± 0.0081	2.5	0.64	0.42
^{14}C (B1)	0.424 ± 0.019	0.4769 ± 0.0044	−11.1	−2.71	−1.90
^{99}Tc (B1)	0.206 ± 0.011	0.2076 ± 0.0025	−0.8	−0.14	−0.13
^{54}Mn (GH)	5.04 ± 0.18	5.091 ± 0.029	−1.0	−0.28	−0.17
^{60}Co (GH)	2.224 ± 0.087	2.3900 ± 0.0095	−6.9	−1.90	−1.19
^{65}Zn (GH)	2.59 ± 0.11	2.612 ± 0.023	−0.8	−0.20	−0.14
^{133}Ba (GH)	25.96 ± 0.96	28.26 ± 0.20	−8.1	−2.35	−1.40
^{137}Cs (GH)	39.1 ± 1.4	39.72 ± 0.29	−1.6	−0.43	−0.27
^{134}Cs (GL)	10.43 ± 0.41	10.600 ± 0.076	−1.6	−0.41	−0.28
^{137}Cs (GL)	6.82 ± 0.30	6.733 ± 0.061	1.3	0.28	0.22
^{210}Pb (GL)	18.1 ± 2.6	23.94 ± 0.25	−24.4	−2.24	−4.19
^{241}Am (GL)	23.79 ± 0.95	23.83 ± 0.10	−0.2	−0.04	−0.03


Deviation (%) of Laboratory 38
50
0
-50
3H (AB)
90Sr (AB)
241Am (AB)
244Cm (AB)
238U (A1)
238Pu (A1)
241Am (A1)
3H (B1)
14C (B1)
99Tc (B1)
54Mn (GH)
60Co (GH)
65Zn (GH)
133Ba (GH)
137Cs (GH)

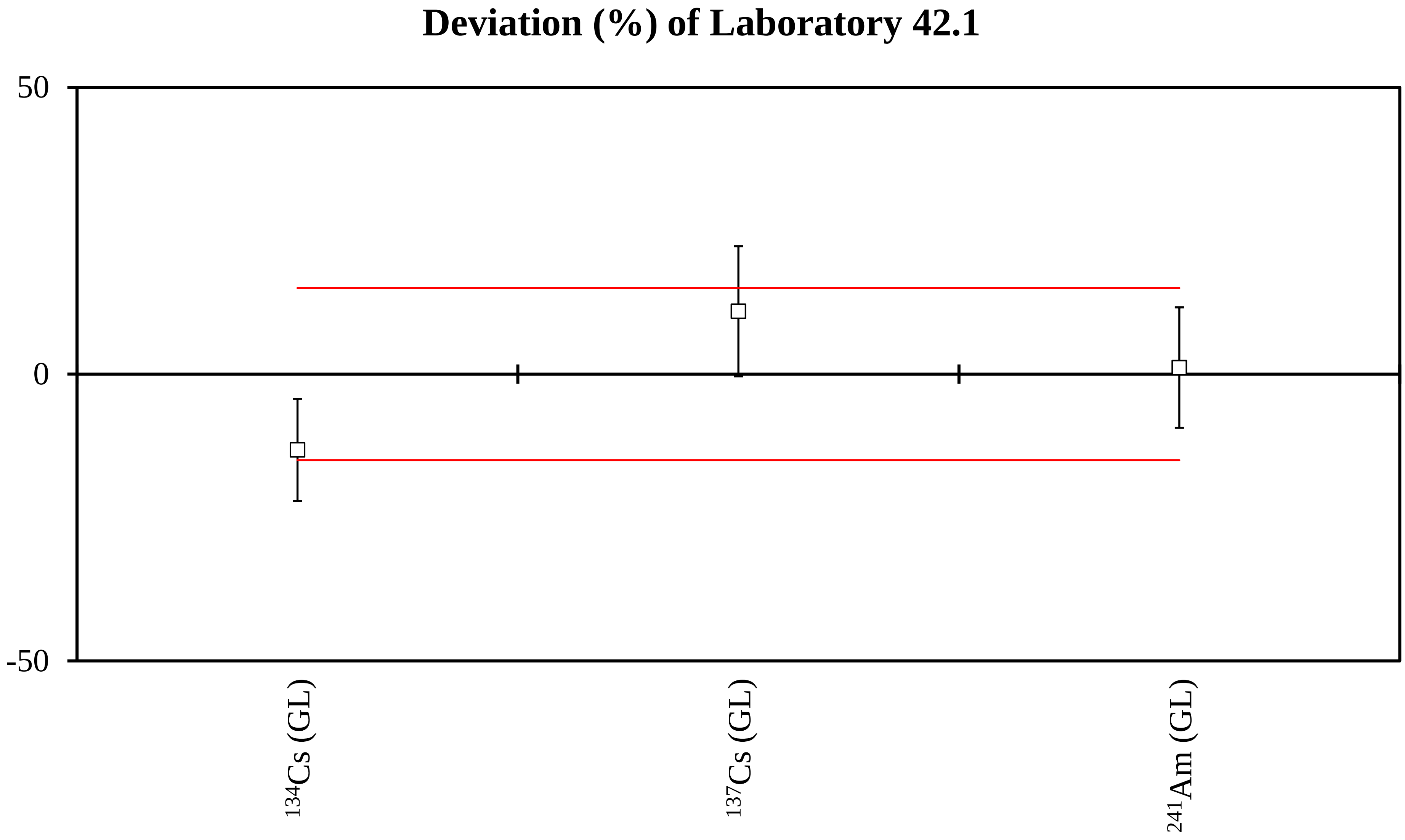
Radionuclide	Laboratory 38	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	15.0 ± 2.0	14.22 ± 0.15	5.5	0.39	0.94
^{90}Sr (AB)	5.20 ± 0.50	6.266 ± 0.016	−17.0	−2.13	−2.92
^{241}Am (AB)	6.6 ± 0.7	7.761 ± 0.031	−15.0	−1.66	−2.57
^{244}Cm (AB)	3.80 ± 0.40	5.0547 ± 0.0073	−24.8	−3.14	−4.26
^{238}U (A1)	4.60 ± 0.50	4.861 ± 0.083	−5.4	−0.51	−0.92
^{238}Pu (A1)	1.90 ± 0.20	2.1690 ± 0.0054	−12.4	−1.34	−2.13
^{241}Am (A1)	14.0 ± 2.0	15.841 ± 0.067	−11.6	−0.92	−2.00
^{3}H (B1)	0.67 ± 0.09	0.5885 ± 0.0081	13.8	0.90	2.38
^{14}C (B1)	0.500 ± 0.050	0.4769 ± 0.0044	4.8	0.46	0.83
^{99}Tc (B1)	0.20 ± 0.03	0.2076 ± 0.0025	−3.7	−0.25	−0.63
^{54}Mn (GH)	4.9 ± 0.3	5.091 ± 0.029	−3.8	−0.63	−0.64
^{60}Co (GH)	2.40 ± 0.20	2.3900 ± 0.0095	0.4	0.05	0.07
^{65}Zn (GH)	2.50 ± 0.20	2.612 ± 0.023	−4.3	−0.56	−0.74
^{133}Ba (GH)	27.0 ± 2.0	28.26 ± 0.20	−4.5	−0.63	−0.77
^{137}Cs (GH)	39.0 ± 3.0	39.72 ± 0.29	−1.8	−0.24	−0.31


Deviation (%) of Laboratory 40
50
0
-50
90Sr (AB)
238Pu (A1)
241Am (A1)
134Cs (GL)
137Cs (GL)
210Pb (GL)
241Am (GL)

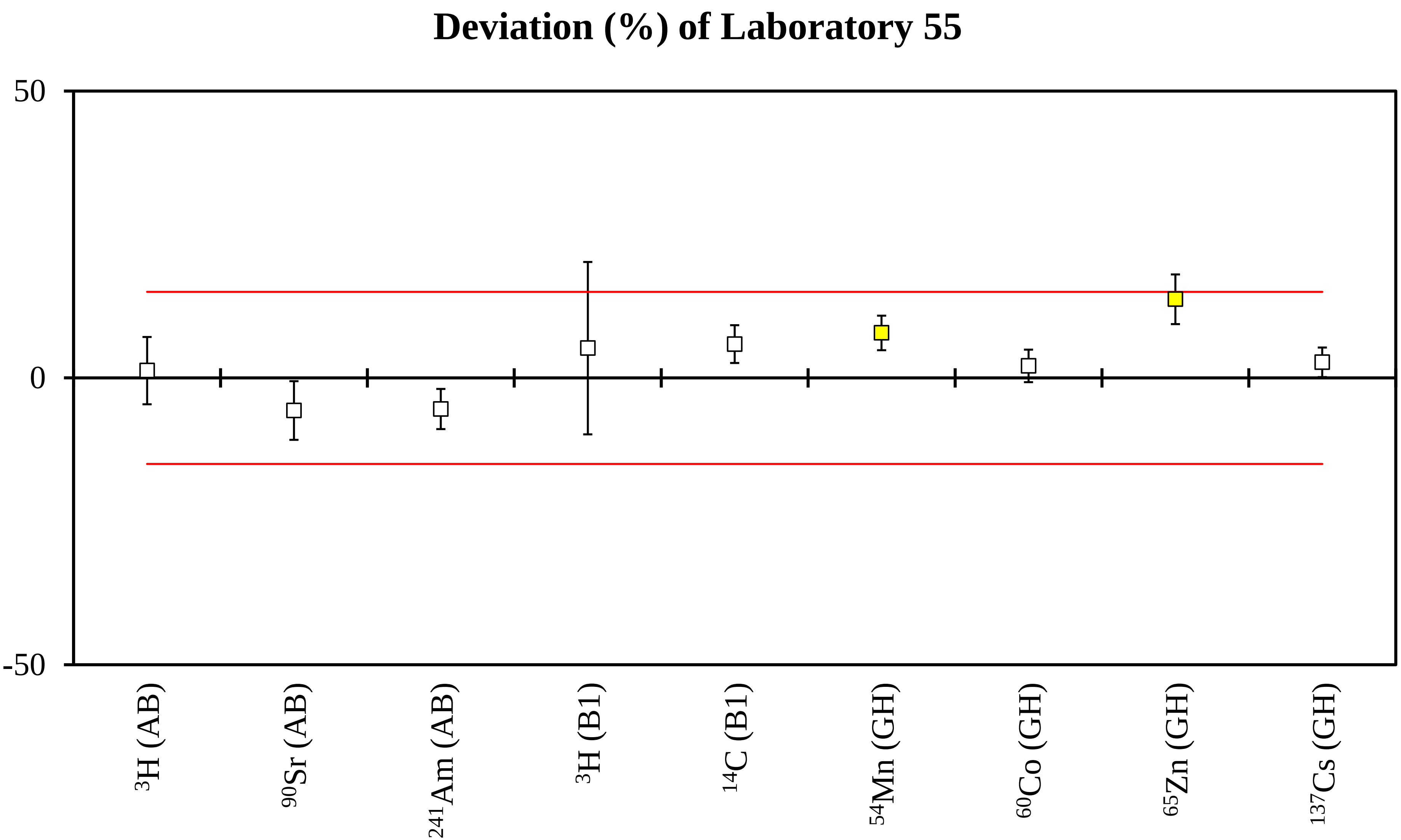
Radionuclide	Laboratory 40	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{90}Sr (AB)	6.1 ± 1.2	6.266 ± 0.016	−2.6	−0.14	−0.45
^{238}Pu (A1)	2.118 ± 0.056	2.1690 ± 0.0054	−2.4	−0.91	−0.40
^{241}Am (A1)	15.04 ± 0.40	15.841 ± 0.067	−5.1	−1.97	−0.87
^{134}Cs (GL)	9.95 ± 0.61	10.600 ± 0.076	−6.1	−1.06	−1.05
^{137}Cs (GL)	6.58 ± 0.40	6.733 ± 0.061	−2.3	−0.38	−0.39
^{210}Pb (GL)	22.4 ± 1.4	23.94 ± 0.25	−6.4	−1.08	−1.10
^{241}Am (GL)	23.0 ± 1.4	23.83 ± 0.10	−3.5	−0.59	−0.60


Deviation (%) of Laboratory 41
50
0
-50
3H (AB)
90Sr (AB)
3H (B1)
54Mn (GH)
60Co (GH)
65Zn (GH)
133Ba (GH)
137Cs (GH)
134Cs (GL)
137Cs (GL)
210Pb (GL)
241Am (GL)

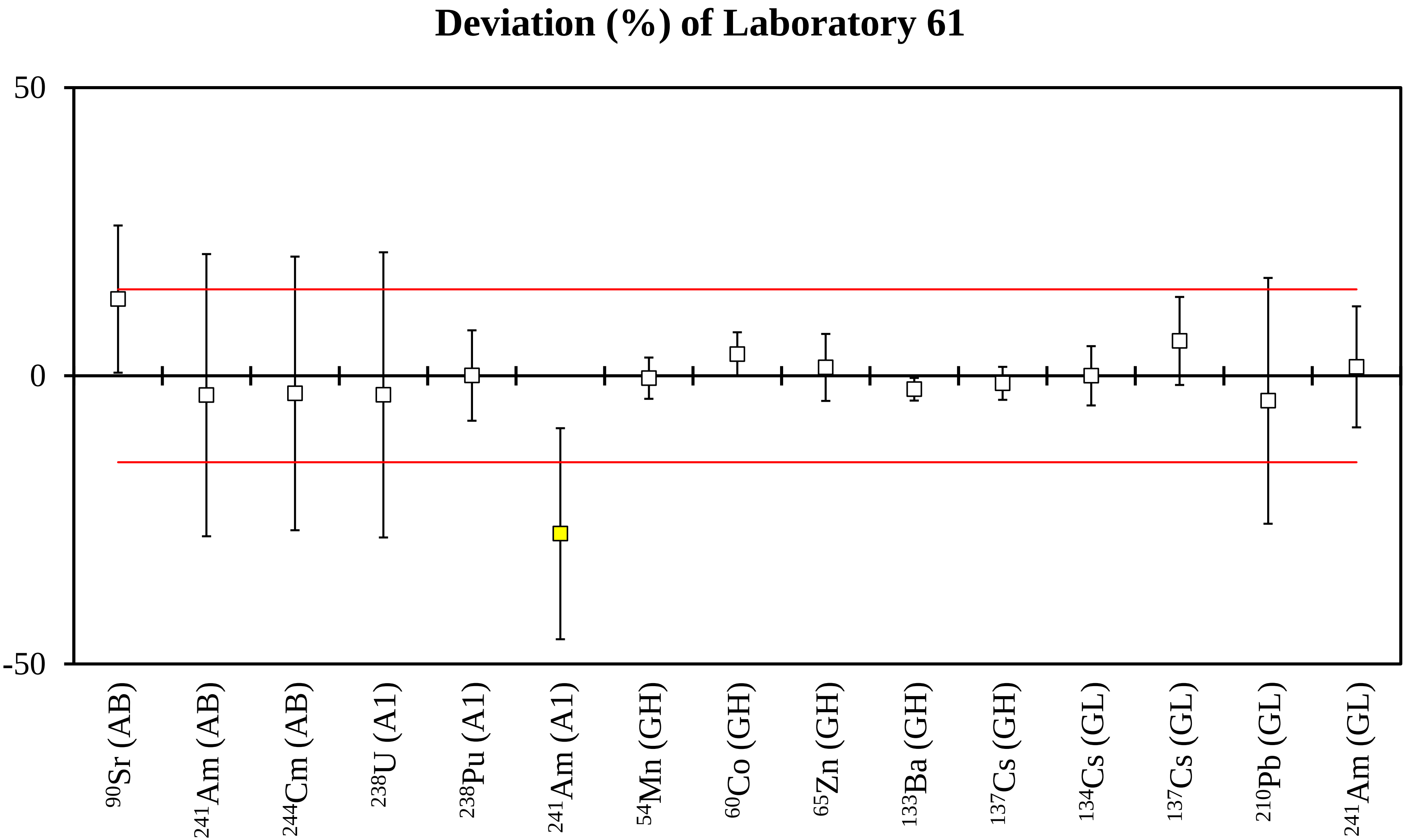
Radionuclide	Laboratory 41	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	13.3 ± 1.2	14.22 ± 0.15	−6.5	−0.76	−1.11
^{90}Sr (AB)	6.12 ± 0.63	6.266 ± 0.016	−2.3	−0.23	−0.40
^{3}H (B1)	0.500 ± 0.040	0.5885 ± 0.0081	−15.0	−2.17	−2.58
^{54}Mn (GH)	5.00 ± 0.26	5.091 ± 0.029	−1.8	−0.35	−0.31
^{60}Co (GH)	2.319 ± 0.080	2.3900 ± 0.0095	−3.0	−0.88	−0.51
^{65}Zn (GH)	2.65 ± 0.13	2.612 ± 0.023	1.5	0.29	0.25
^{133}Ba (GH)	28.94 ± 0.77	28.26 ± 0.20	2.4	0.85	0.41
^{137}Cs (GH)	38.3 ± 1.8	39.72 ± 0.29	−3.6	−0.78	−0.61
^{134}Cs (GL)	9.58 ± 0.35	10.600 ± 0.076	−9.6	−2.85	−1.65
^{137}Cs (GL)	6.70 ± 0.38	6.733 ± 0.061	−0.5	−0.09	−0.08
^{210}Pb (GL)	17.1 ± 4.4	23.94 ± 0.25	−28.6	−1.55	−4.91
^{241}Am (GL)	23.4 ± 1.5	23.83 ± 0.10	−1.8	−0.29	−0.31


Deviation (%) of Laboratory 42.1
50
0
-50
^{134}Cs (GL)
^{137}Cs (GL)
^{241}Am (GL)

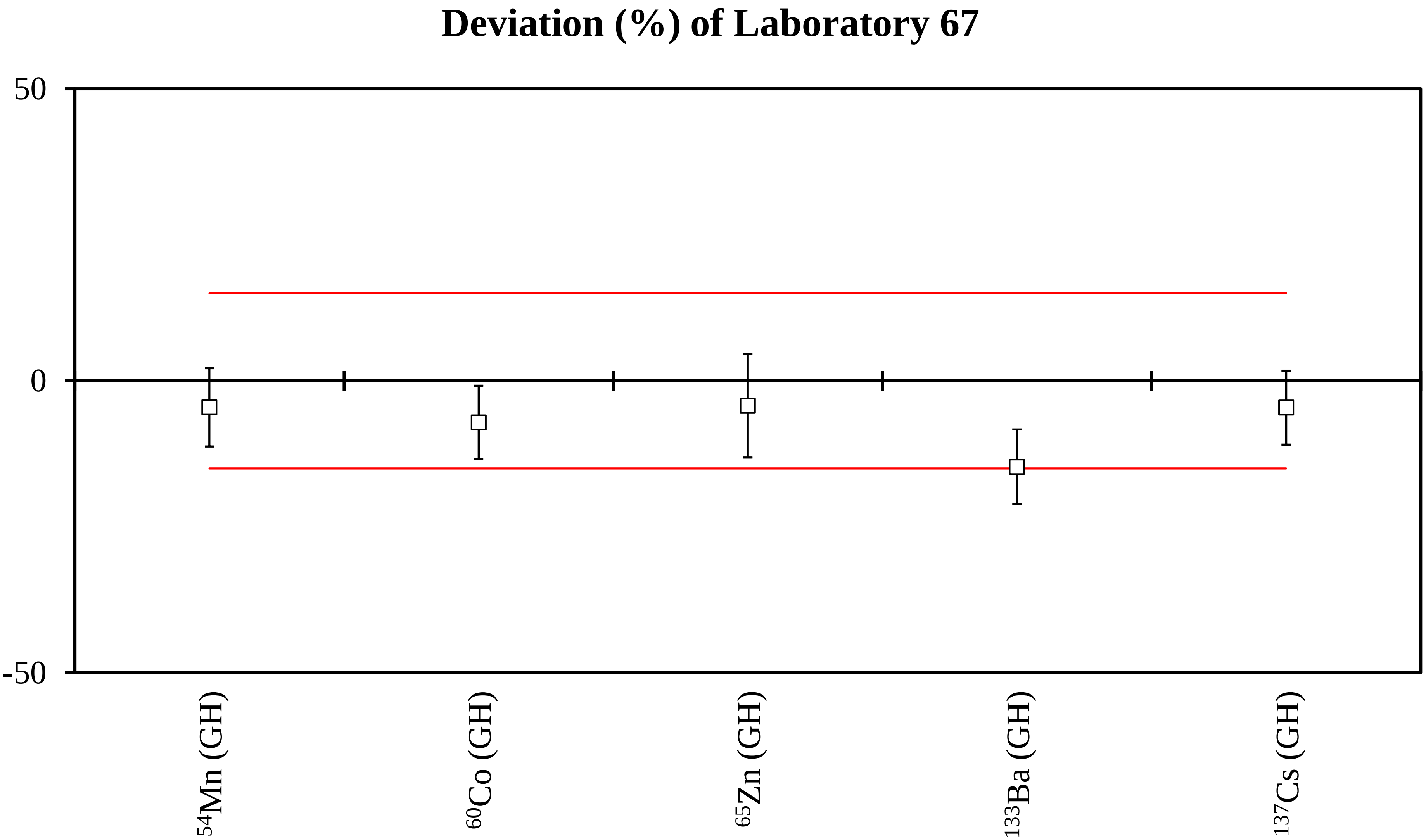
Radionuclide	Laboratory 42.1	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{134}Cs (GL)	9.20 ± 0.94	10.600 ± 0.076	−13.2	−1.48	−2.27
^{137}Cs (GL)	7.47 ± 0.76	6.733 ± 0.061	10.9	0.97	1.88
^{241}Am (GL)	24.1 ± 2.5	23.83 ± 0.10	1.1	0.11	0.19


Deviation (%) of Laboratory 55
50
0
-50
3H (AB)
90Sr (AB)
241Am (AB)
3H (B1)
14C (B1)
54Mn (GH)
60Co (GH)
65Zn (GH)
137Cs (GH)

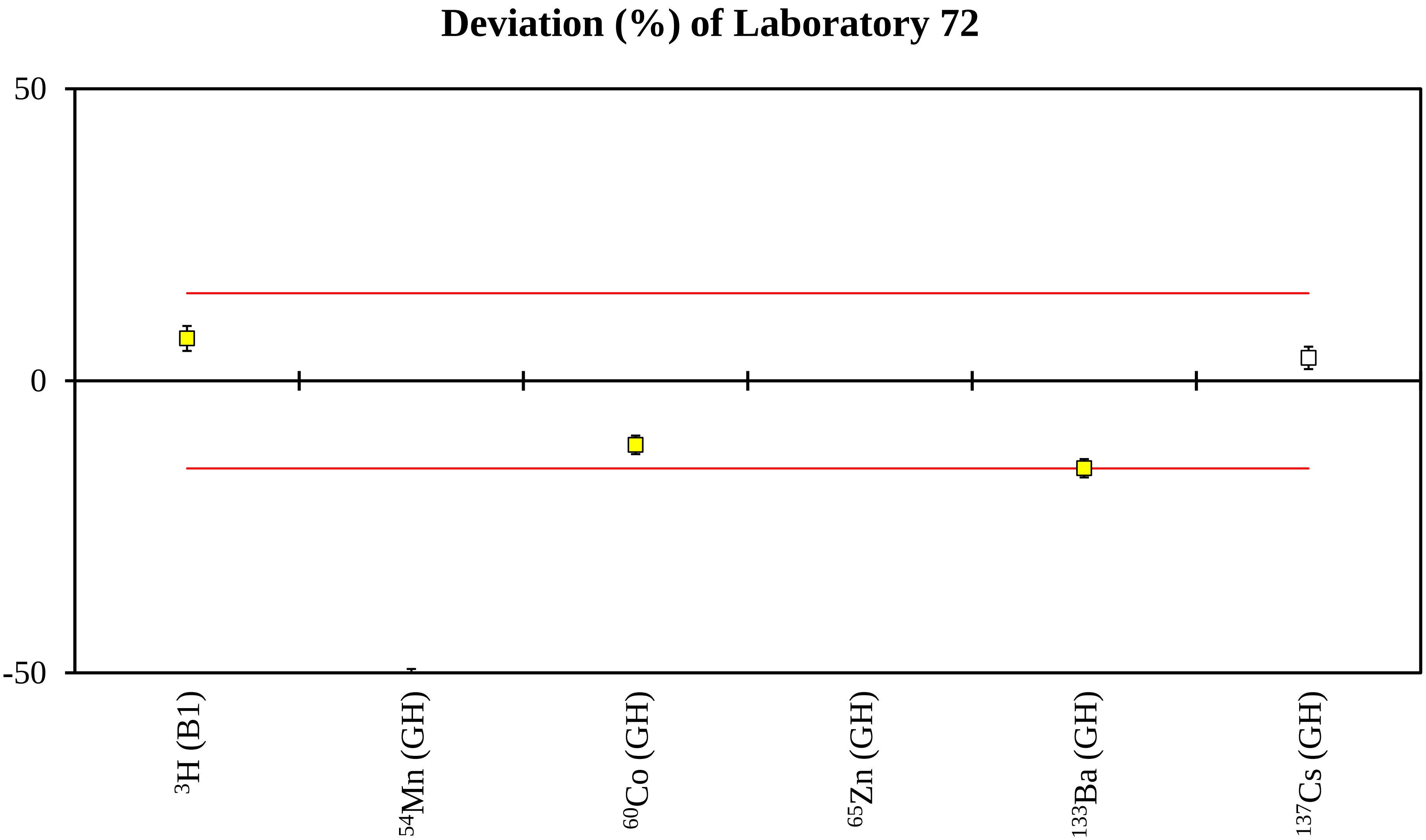
Radionuclide	Laboratory 55	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	14.40 ± 0.82	14.22 ± 0.15	1.3	0.22	0.22
^{90}Sr (AB)	5.91 ± 0.32	6.266 ± 0.016	−5.7	−1.11	−0.98
^{241}Am (AB)	7.34 ± 0.27	7.761 ± 0.031	−5.4	−1.55	−0.93
^{3}H (B1)	0.619 ± 0.088	0.5885 ± 0.0081	5.2	0.35	0.89
^{14}C (B1)	0.505 ± 0.015	0.4769 ± 0.0044	5.9	1.80	1.01
^{54}Mn (GH)	5.49 ± 0.15	5.091 ± 0.029	7.8	2.61	1.35
^{60}Co (GH)	2.440 ± 0.067	2.3900 ± 0.0095	2.1	0.74	0.36
^{65}Zn (GH)	2.97 ± 0.11	2.612 ± 0.023	13.7	3.19	2.35
^{137}Cs (GH)	40.80 ± 0.98	39.72 ± 0.29	2.7	1.06	0.47


Deviation (%) of Laboratory 61
50
0
-50
90Sr (AB)
241Am (AB)
244Cm (AB)
238U (A1)
238Pu (A1)
241Am (A1)
54Mn (GH)
60Co (GH)
65Zn (GH)
133Ba (GH)
137Cs (GH)
134Cs (GL)
137Cs (GL)
210Pb (GL)
241Am (GL)

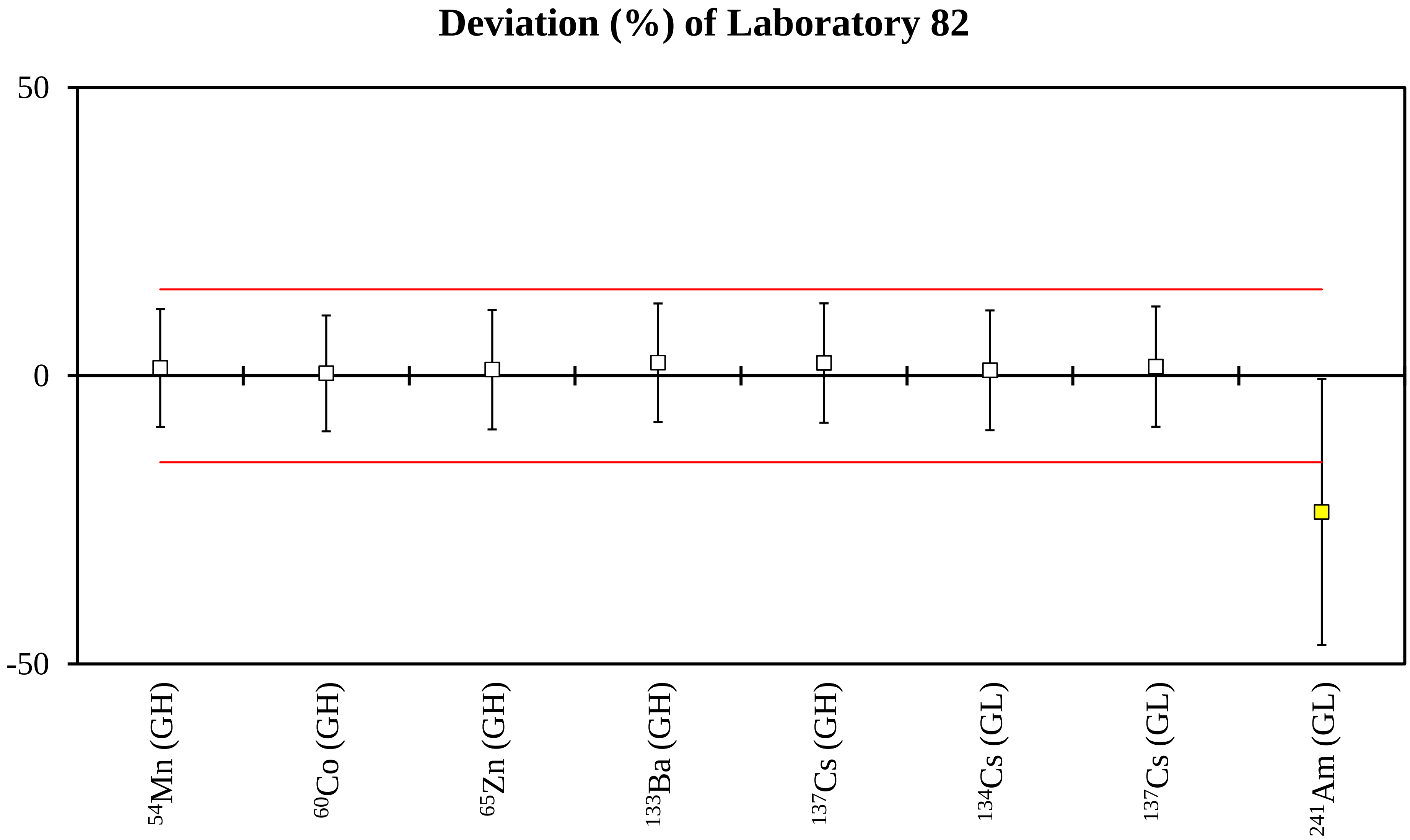
Radionuclide	Laboratory 61	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{90}Sr (AB)	7.10 ± 0.80	6.266 ± 0.016	13.3	1.04	2.29
^{241}Am (AB)	7.5 ± 1.9	7.761 ± 0.031	−3.4	−0.14	−0.58
^{244}Cm (AB)	4.9 ± 1.2	5.0547 ± 0.0073	−3.1	−0.13	−0.53
^{238}U (A1)	4.7 ± 1.2	4.861 ± 0.083	−3.3	−0.13	−0.57
^{238}Pu (A1)	2.17 ± 0.17	2.1690 ± 0.0054	0.0	0.01	0.01
^{241}Am (A1)	11.5 ± 2.9	15.841 ± 0.067	−27.4	−1.50	−4.71
^{54}Mn (GH)	5.07 ± 0.18	5.091 ± 0.029	−0.4	−0.12	−0.07
^{60}Co (GH)	2.48 ± 0.09	2.3900 ± 0.0095	3.8	0.99	0.65
^{65}Zn (GH)	2.65 ± 0.15	2.612 ± 0.023	1.5	0.25	0.25
^{133}Ba (GH)	27.60 ± 0.52	28.26 ± 0.20	−2.3	−1.18	−0.40
^{137}Cs (GH)	39.2 ± 1.1	39.72 ± 0.29	−1.3	−0.46	−0.22
^{134}Cs (GL)	10.60 ± 0.54	10.600 ± 0.076	0.0	0.00	0.00
^{137}Cs (GL)	7.14 ± 0.51	6.733 ± 0.061	6.0	0.79	1.04
^{210}Pb (GL)	22.9 ± 5.1	23.94 ± 0.25	−4.3	−0.20	−0.75
^{241}Am (GL)	24.2 ± 2.5	23.83 ± 0.10	1.6	0.15	0.27


Deviation (%) of Laboratory 67
50
0
-50
^{54}Mn (GH)
^{60}Co (GH)
^{65}Zn (GH)
^{133}Ba (GH)
^{137}Cs (GH)

Radionuclide	Laboratory 67	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{54}Mn (GH)	4.86 ± 0.34	5.091 ± 0.029	−4.5	−0.68	−0.78
^{60}Co (GH)	2.22 ± 0.15	2.3900 ± 0.0095	−7.1	−1.13	−1.22
^{65}Zn (GH)	2.50 ± 0.23	2.612 ± 0.023	−4.3	−0.48	−0.74
^{133}Ba (GH)	24.1 ± 1.8	28.26 ± 0.20	−14.7	−2.30	−2.53
^{137}Cs (GH)	37.9 ± 2.5	39.72 ± 0.29	−4.6	−0.72	−0.79

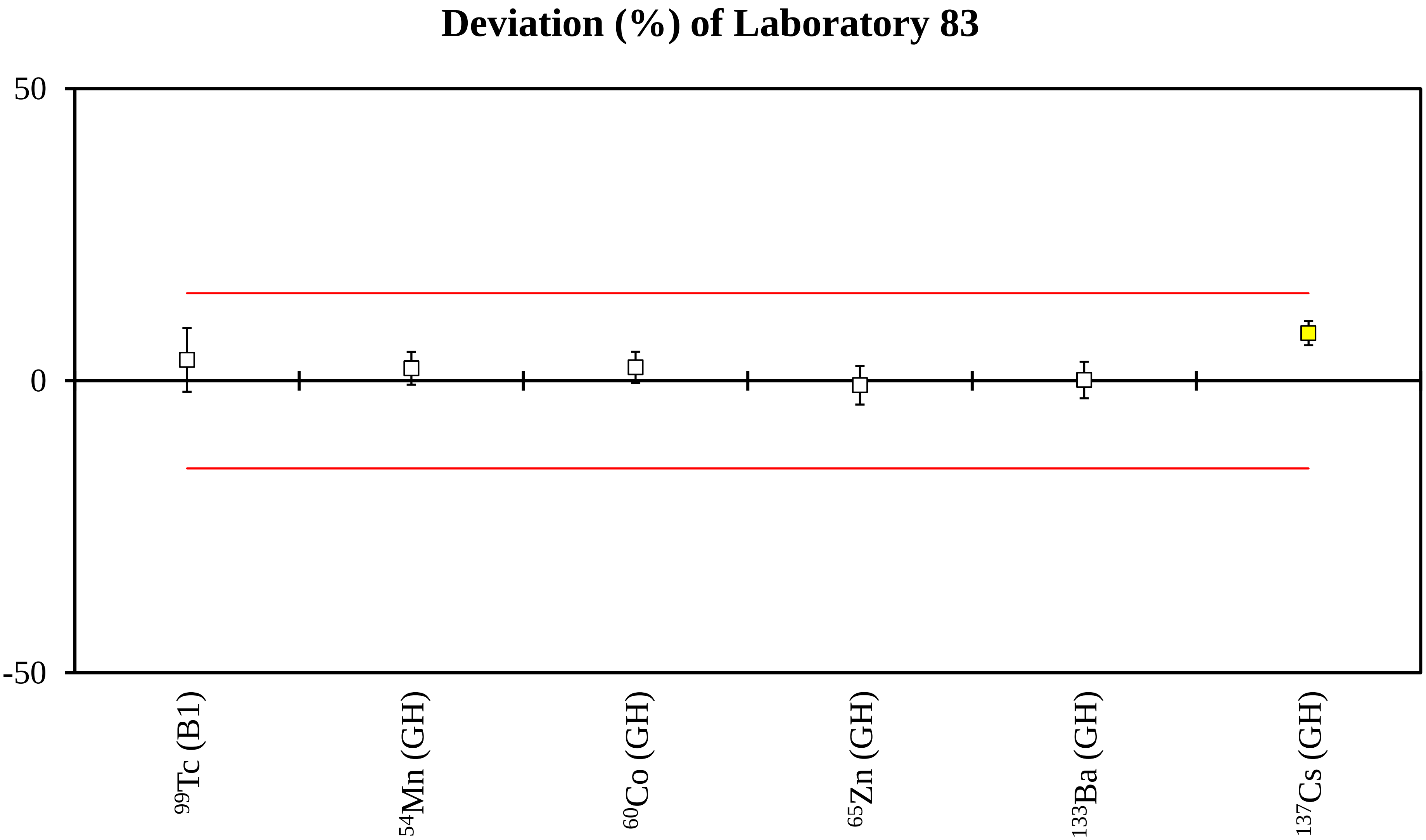

Deviation (%) of Laboratory 72
50
0
-50
3H (B1)
54Mn (GH)
60Co (GH)
65Zn (GH)
133Ba (GH)
137Cs (GH)

Radionuclide	Laboratory 72	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (B1)	0.6312 ± 0.0091	0.5885 ± 0.0081	7.3	3.50	1.25
^{54}Mn (GH)	2.531 ± 0.046	5.091 ± 0.029	−50.3	−47.08	−8.64
^{60}Co (GH)	2.128 ± 0.037	2.3900 ± 0.0095	−11.0	−6.86	−1.88
^{65}Zn (GH)	1.060 ± 0.026	2.612 ± 0.023	−59.4	−44.71	−10.20
^{133}Ba (GH)	24.03 ± 0.41	28.26 ± 0.20	−15.0	−9.27	−2.57
^{137}Cs (GH)	41.280 ± 0.7	39.72 ± 0.29	3.9	2.06	0.67

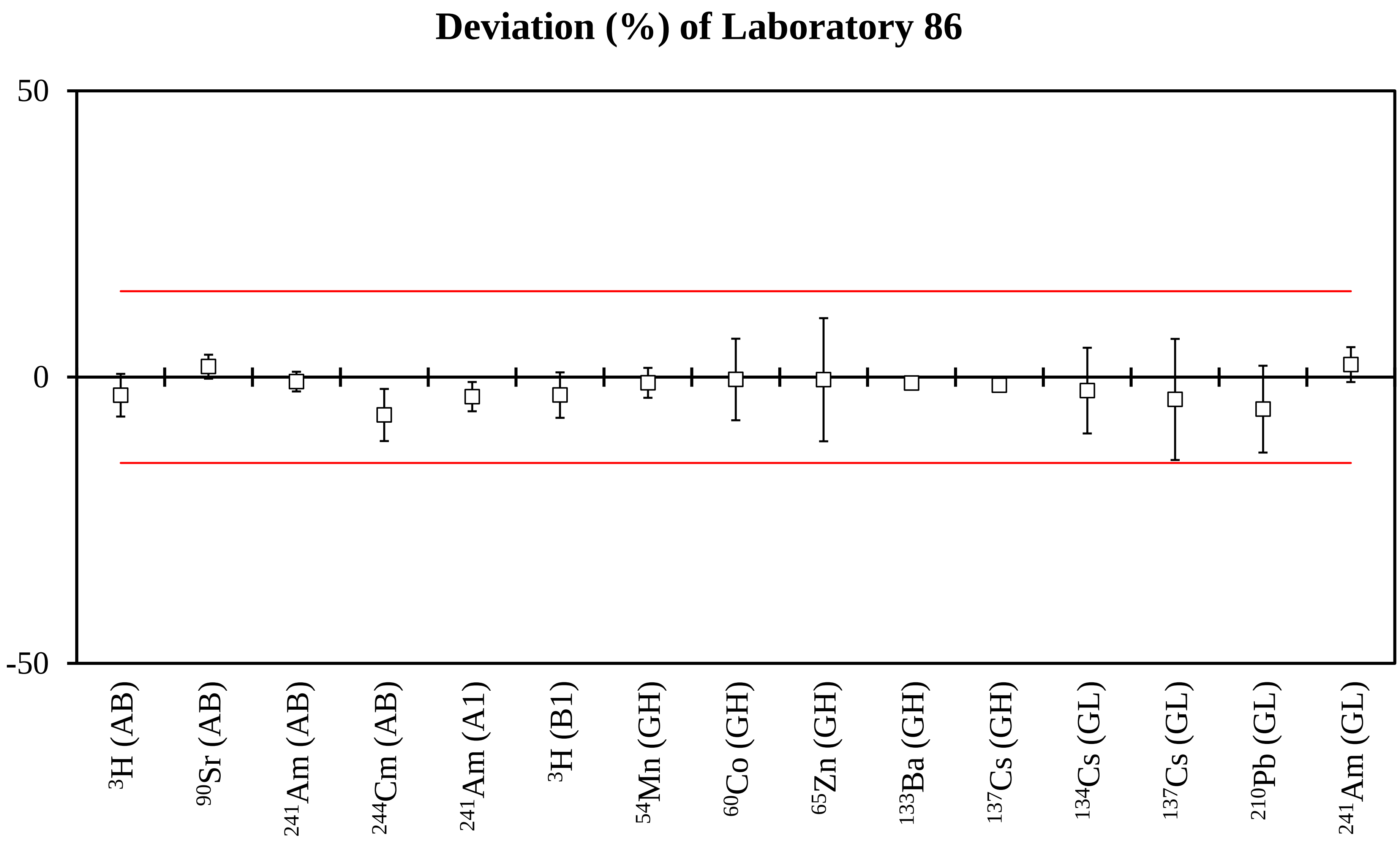


Deviation (%) of Laboratory 82
50
0
-50
^{54}Mn (GH)
^{60}Co (GH)
^{65}Zn (GH)
^{133}Ba (GH)
^{137}Cs (GH)
^{134}Cs (GL)
^{137}Cs (GL)
^{241}Am (GL)

Radionuclide	Laboratory 82	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{54}Mn (GH)	5.16 ± 0.52	5.091 ± 0.029	1.4	0.13	0.23
^{60}Co (GH)	2.40 ± 0.24	2.3900 ± 0.0095	0.4	0.04	0.07
^{65}Zn (GH)	2.64 ± 0.27	2.612 ± 0.023	1.1	0.10	0.18
^{133}Ba (GH)	28.9 ± 2.9	28.26 ± 0.20	2.3	0.22	0.39
^{137}Cs (GH)	40.6 ± 4.1	39.72 ± 0.29	2.2	0.21	0.38
^{134}Cs (GL)	10.7 ± 1.1	10.600 ± 0.076	0.9	0.09	0.16
^{137}Cs (GL)	6.84 ± 0.70	6.733 ± 0.061	1.6	0.15	0.27
^{241}Am (GL)	18.2 ± 5.5	23.83 ± 0.10	−23.6	−1.02	−4.06

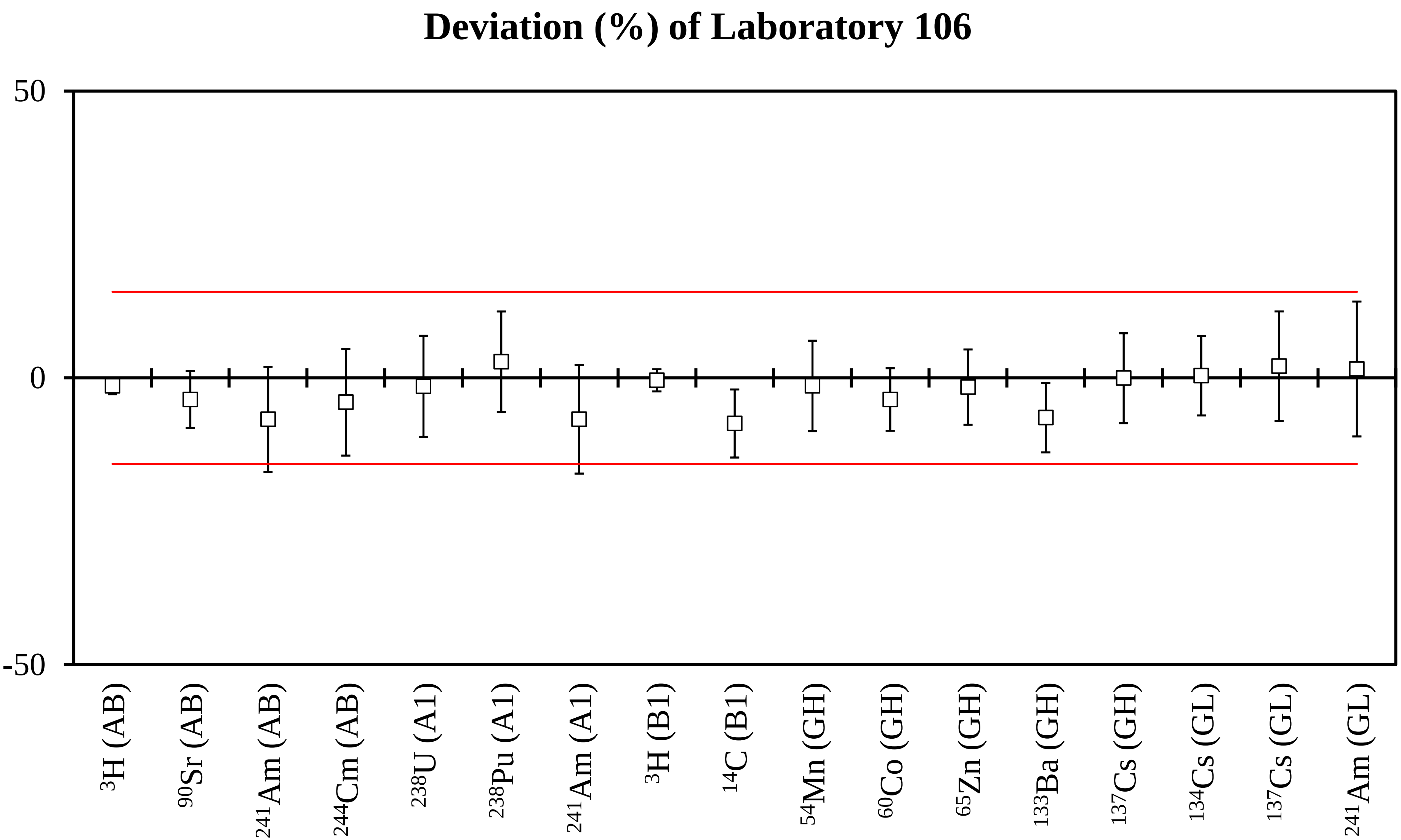

Deviation (%) of Laboratory 83
50
0
-50
99Tc (B1)
54Mn (GH)
60Co (GH)
65Zn (GH)
133Ba (GH)
137Cs (GH)

Radionuclide	Laboratory 83	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{99}Tc (B1)	0.215 ± 0.011	0.2076 ± 0.0025	3.6	0.66	0.61
^{54}Mn (GH)	5.20 ± 0.14	5.091 ± 0.029	2.1	0.76	0.37
^{60}Co (GH)	2.445 ± 0.063	2.3900 ± 0.0095	2.3	0.86	0.40
^{65}Zn (GH)	2.592 ± 0.083	2.612 ± 0.023	−0.8	−0.23	−0.13
^{133}Ba (GH)	28.30 ± 0.86	28.26 ± 0.20	0.1	0.05	0.02
^{137}Cs (GH)	42.96 ± 0.76	39.72 ± 0.29	8.2	3.98	1.40

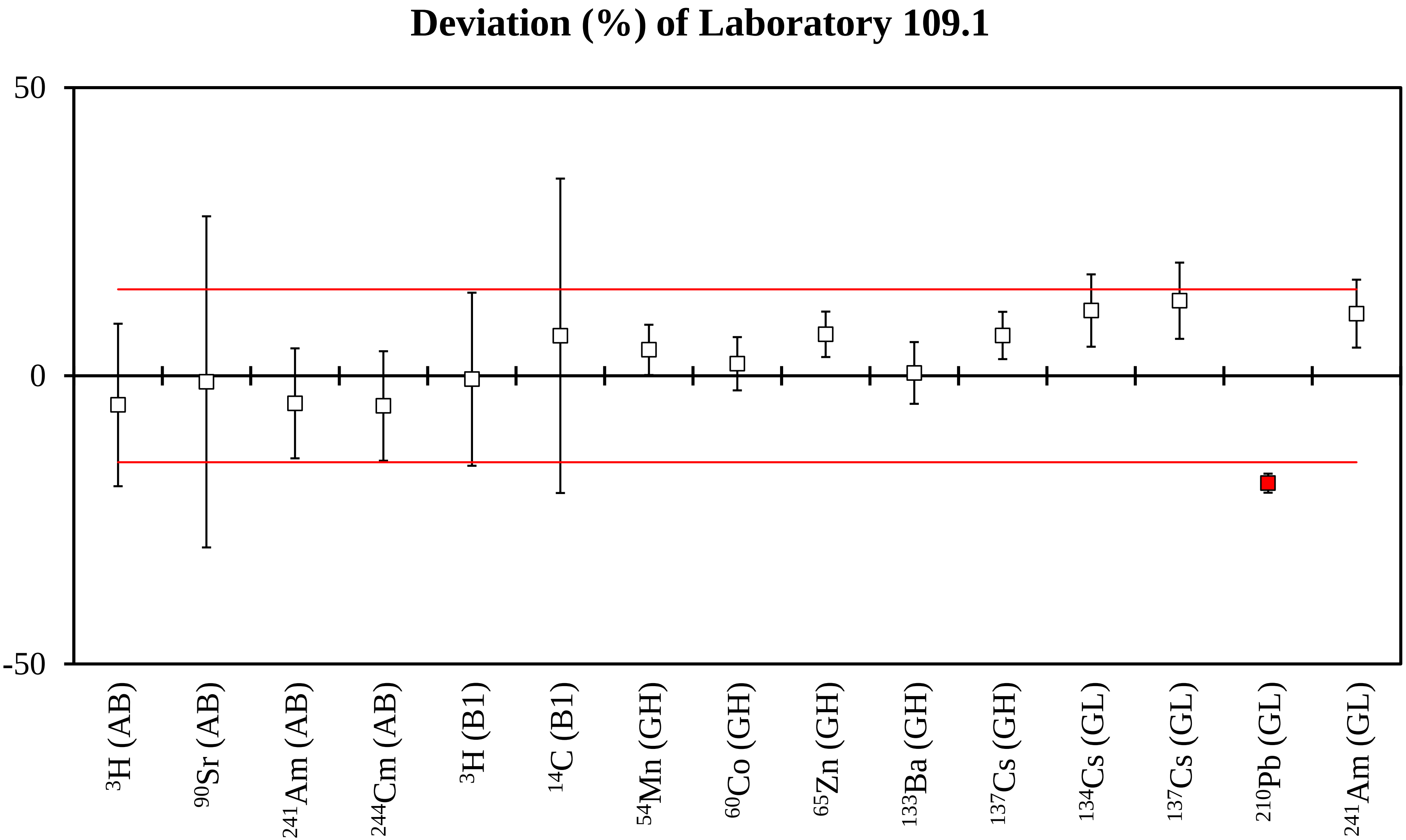


Deviation (%) of Laboratory 86
50
0
-50
3H (AB)
90Sr (AB)
241Am (AB)
244Cm (AB)
241Am (A1)
3H (B1)
54Mn (GH)
60Co (GH)
65Zn (GH)
133Ba (GH)
137Cs (GH)
134Cs (GL)
137Cs (GL)
210Pb (GL)
241Am (GL)

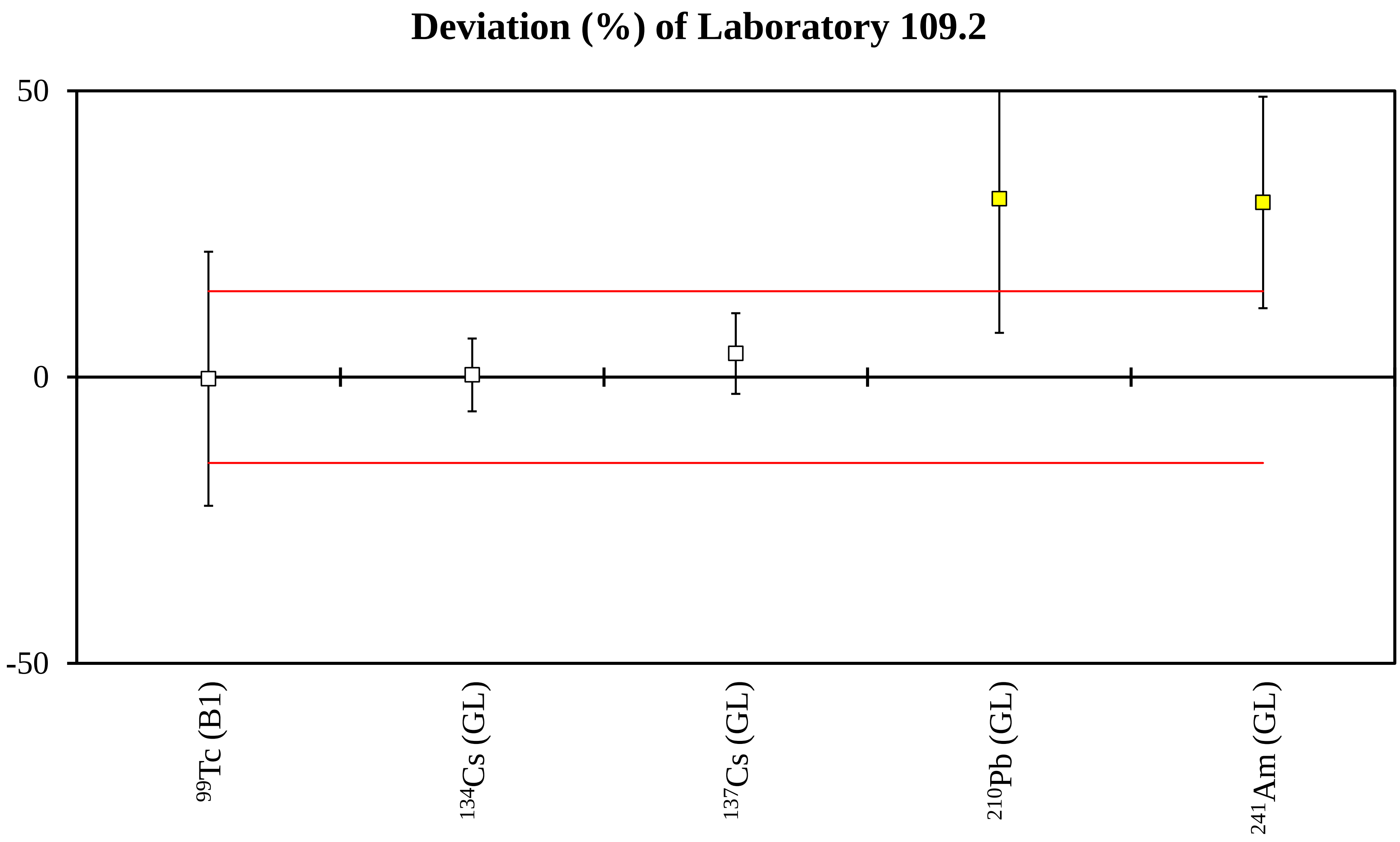
Radionuclide	Laboratory 86	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	13.77 ± 0.51	14.22 ± 0.15	−3.2	−0.85	−0.54
^{90}Sr (AB)	6.38 ± 0.13	6.266 ± 0.016	1.8	0.87	0.31
^{241}Am (AB)	7.70 ± 0.13	7.761 ± 0.031	−0.8	−0.46	−0.13
^{244}Cm (AB)	4.72 ± 0.23	5.0547 ± 0.0073	−6.6	−1.45	−1.14
^{241}Am (A1)	15.30 ± 0.40	15.841 ± 0.067	−3.4	−1.33	−0.59
^{3}H (B1)	0.570 ± 0.022	0.5885 ± 0.0081	−3.1	−0.79	−0.54
^{54}Mn (GH)	5.04 ± 0.13	5.091 ± 0.029	−1.0	−0.38	−0.17
^{60}Co (GH)	2.38 ± 0.17	2.3900 ± 0.0095	−0.4	−0.06	−0.07
^{65}Zn (GH)	2.60 ± 0.28	2.612 ± 0.023	−0.5	−0.04	−0.08
^{133}Ba (GH)	27.968 ± 0.087	28.26 ± 0.20	−1.0	−1.34	−0.18
^{137}Cs (GH)	39.145 ± 0.086	39.72 ± 0.29	−1.4	−1.90	−0.25
^{134}Cs (GL)	10.35 ± 0.79	10.600 ± 0.076	−2.4	−0.32	−0.41
^{137}Cs (GL)	6.47 ± 0.71	6.733 ± 0.061	−3.9	−0.37	−0.67
^{210}Pb (GL)	22.6 ± 1.8	23.94 ± 0.25	−5.6	−0.74	−0.96
^{241}Am (GL)	24.35 ± 0.72	23.83 ± 0.10	2.2	0.72	0.37


Deviation (%) of Laboratory 106
50
0
-50
3H (AB)
90Sr (AB)
241Am (AB)
244Cm (AB)
238U (A1)
238Pu (A1)
241Am (A1)
3H (B1)
14C (B1)
54Mn (GH)
60Co (GH)
65Zn (GH)
133Ba (GH)
137Cs (GH)
134Cs (GL)
137Cs (GL)
241Am (GL)

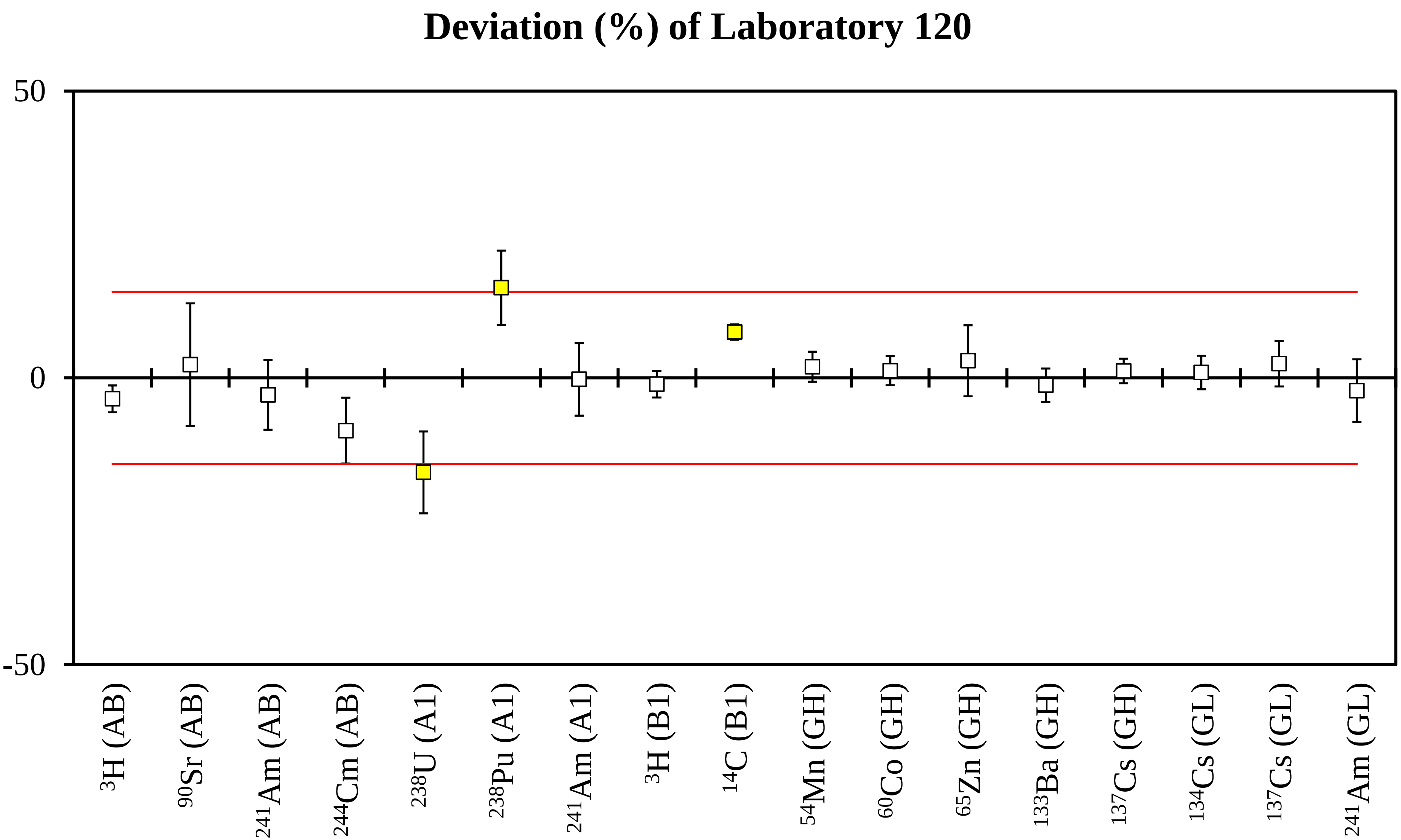
Radionuclide	Laboratory 106	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	14.02 ± 0.14	14.22 ± 0.15	−1.4	−0.97	−0.24
^{90}Sr (AB)	6.03 ± 0.31	6.266 ± 0.016	−3.8	−0.76	−0.65
^{241}Am (AB)	7.20 ± 0.71	7.761 ± 0.031	−7.2	−0.79	−1.24
^{244}Cm (AB)	4.84 ± 0.47	5.0547 ± 0.0073	−4.2	−0.46	−0.73
^{238}U (A1)	4.79 ± 0.42	4.861 ± 0.083	−1.5	−0.17	−0.25
^{238}Pu (A1)	2.23 ± 0.19	2.1690 ± 0.0054	2.8	0.32	0.48
^{241}Am (A1)	14.7 ± 1.5	15.841 ± 0.067	−7.2	−0.76	−1.24
^{3}H (B1)	0.5860 ± 0.0080	0.5885 ± 0.0081	−0.4	−0.22	−0.07
^{14}C (B1)	0.439 ± 0.028	0.4769 ± 0.0044	−7.9	−1.34	−1.36
^{54}Mn (GH)	5.02 ± 0.40	5.091 ± 0.029	−1.4	−0.18	−0.24
^{60}Co (GH)	2.30 ± 0.13	2.3900 ± 0.0095	−3.8	−0.69	−0.65
^{65}Zn (GH)	2.57 ± 0.17	2.612 ± 0.023	−1.6	−0.24	−0.28
^{133}Ba (GH)	26.3 ± 1.7	28.26 ± 0.20	−6.9	−1.15	−1.19
^{137}Cs (GH)	39.7 ± 3.1	39.72 ± 0.29	−0.1	−0.01	−0.01
^{134}Cs (GL)	10.64 ± 0.73	10.600 ± 0.076	0.4	0.05	0.06
^{137}Cs (GL)	6.87 ± 0.64	6.733 ± 0.061	2.0	0.21	0.35
^{241}Am (GL)	24.2 ± 2.8	23.83 ± 0.10	1.6	0.13	0.27


Deviation (%) of Laboratory 109.1
50
0
-50
^{3}H (AB)
^{90}Sr (AB)
^{241}Am (AB)
^{244}Cm (AB)
^{3}H (B1)
^{14}C (B1)
^{54}Mn (GH)
^{60}Co (GH)
^{65}Zn (GH)
^{133}Ba (GH)
^{137}Cs (GH)
^{134}Cs (GL)
^{137}Cs (GL)
^{210}Pb (GL)
^{241}Am (GL)

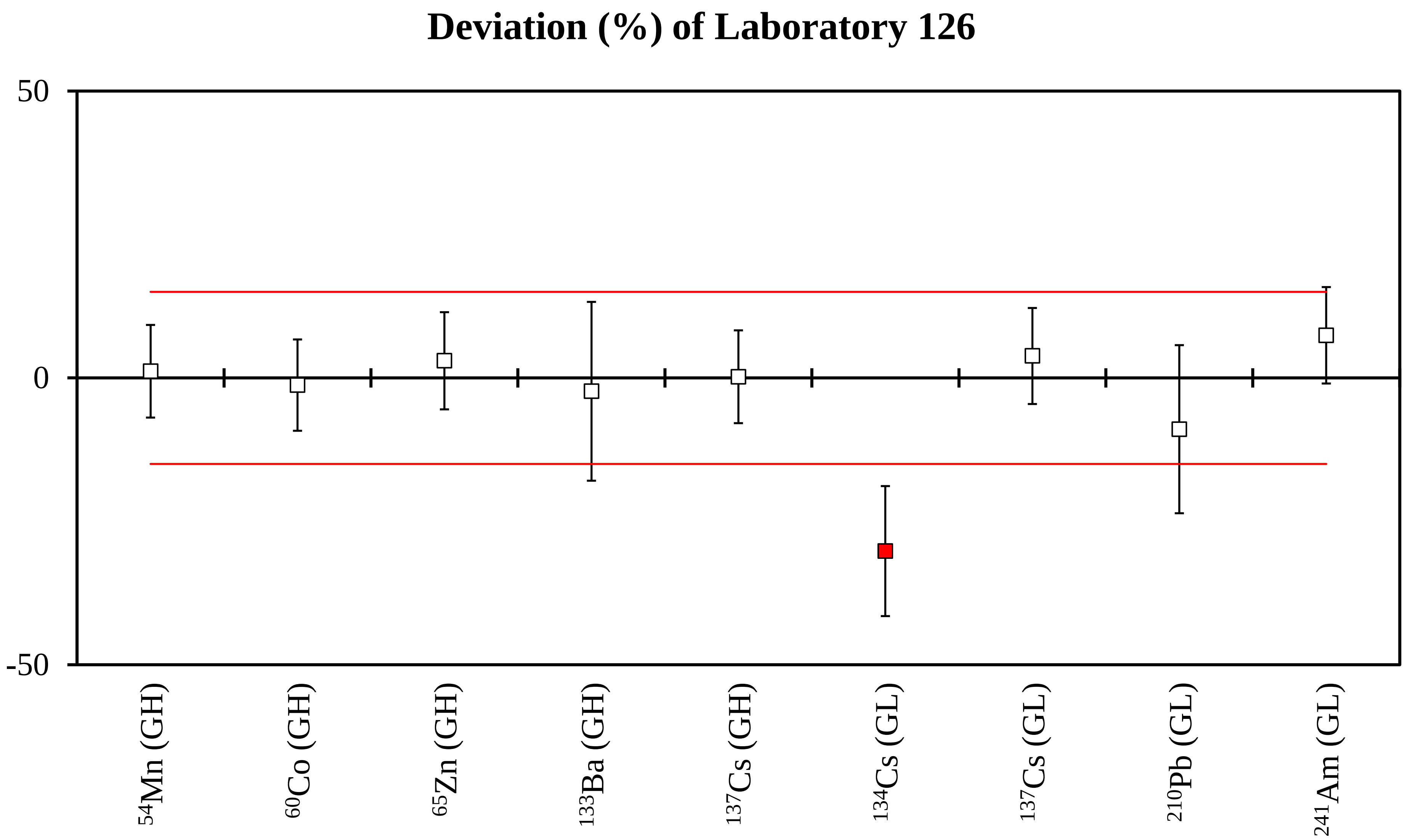
Radionuclide	Laboratory 109.1	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	13.5 ± 2.0	14.22 ± 0.15	−5.1	−0.36	−0.87
^{90}Sr (AB)	6.2 ± 1.8	6.266 ± 0.016	−1.1	−0.04	−0.18
^{241}Am (AB)	7.39 ± 0.74	7.761 ± 0.031	−4.8	−0.50	−0.82
^{244}Cm (AB)	4.79 ± 0.48	5.0547 ± 0.0073	−5.2	−0.55	−0.90
^{3}H (B1)	0.585 ± 0.088	0.5885 ± 0.0081	−0.6	−0.04	−0.10
^{14}C (B1)	0.51 ± 0.13	0.4769 ± 0.0044	6.9	0.25	1.19
^{54}Mn (GH)	5.32 ± 0.22	5.091 ± 0.029	4.5	1.03	0.77
^{60}Co (GH)	2.44 ± 0.11	2.3900 ± 0.0095	2.1	0.45	0.36
^{65}Zn (GH)	2.80 ± 0.10	2.612 ± 0.023	7.2	1.83	1.24
^{133}Ba (GH)	28.4 ± 1.5	28.26 ± 0.20	0.5	0.09	0.09
^{137}Cs (GH)	42.5 ± 1.6	39.72 ± 0.29	7.0	1.71	1.20
^{134}Cs (GL)	11.80 ± 0.66	10.600 ± 0.076	11.3	1.81	1.94
^{137}Cs (GL)	7.61 ± 0.44	6.733 ± 0.061	13.0	1.97	2.24
^{210}Pb (GL)	19.48 ± 0.34	23.94 ± 0.25	−18.6	−10.57	−3.20
^{241}Am (GL)	26.4 ± 1.4	23.83 ± 0.10	10.8	1.83	1.85


Deviation (%) of Laboratory 109.2
50
0
-50
99Tc (B1)
134Cs (GL)
137Cs (GL)
210Pb (GL)
241Am (GL)

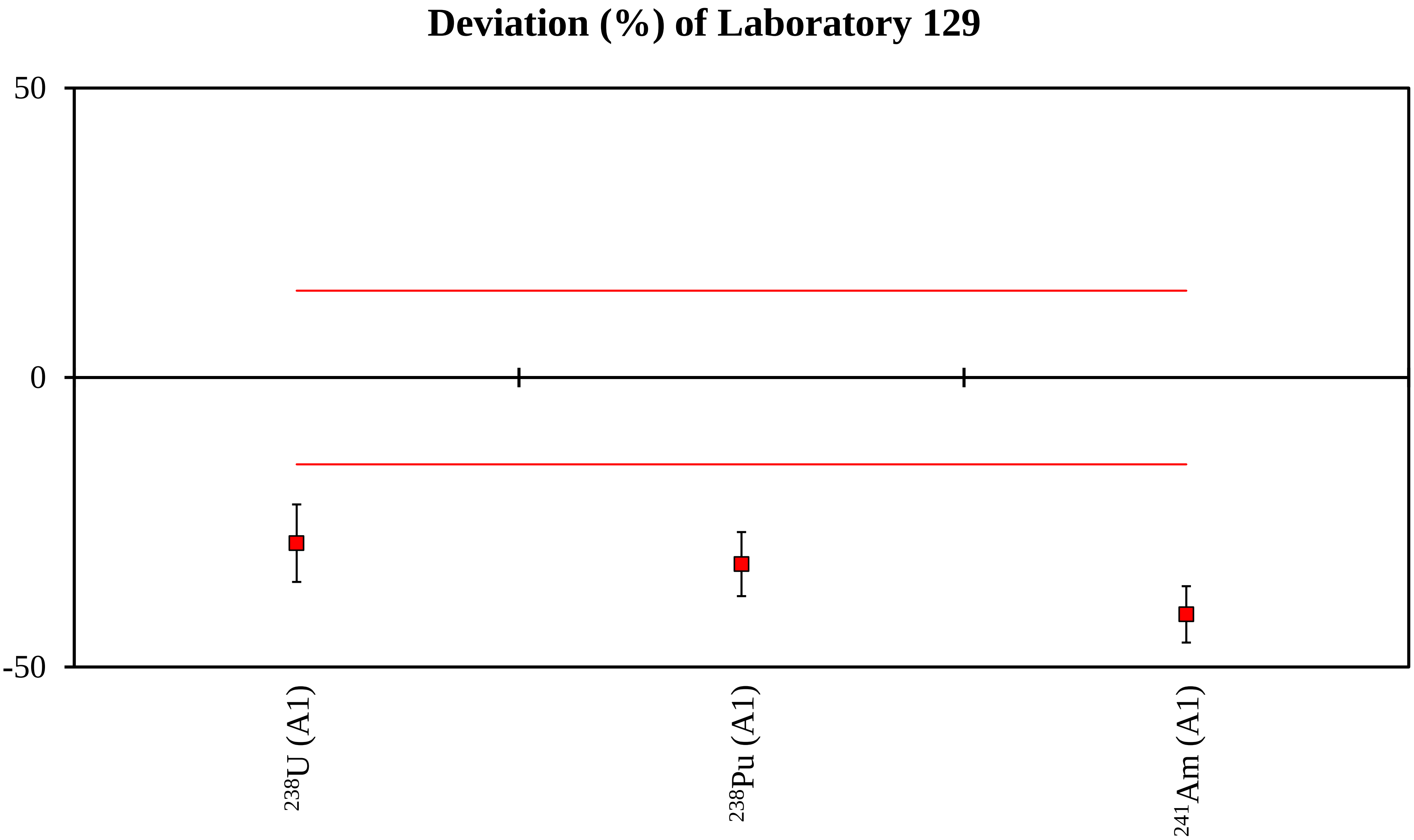
Radionuclide	Laboratory 109.2	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{99}Tc (B1)	0.207 ± 0.046	0.2076 ± 0.0025	−0.3	−0.01	−0.05
^{134}Cs (GL)	10.64 ± 0.67	10.600 ± 0.076	0.4	0.06	0.06
^{137}Cs (GL)	7.01 ± 0.47	6.733 ± 0.061	4.1	0.58	0.71
^{210}Pb (GL)	31.4 ± 5.6	23.94 ± 0.25	31.2	1.33	5.35
^{241}Am (GL)	31.1 ± 4.4	23.83 ± 0.10	30.5	1.65	5.24


Deviation (%) of Laboratory 120
50
0
-50
3H (AB)
90Sr (AB)
241Am (AB)
244Cm (AB)
238U (A1)
238Pu (A1)
241Am (A1)
3H (B1)
14C (B1)
54Mn (GH)
60Co (GH)
65Zn (GH)
133Ba (GH)
137Cs (GH)
134Cs (GL)
137Cs (GL)
241Am (GL)

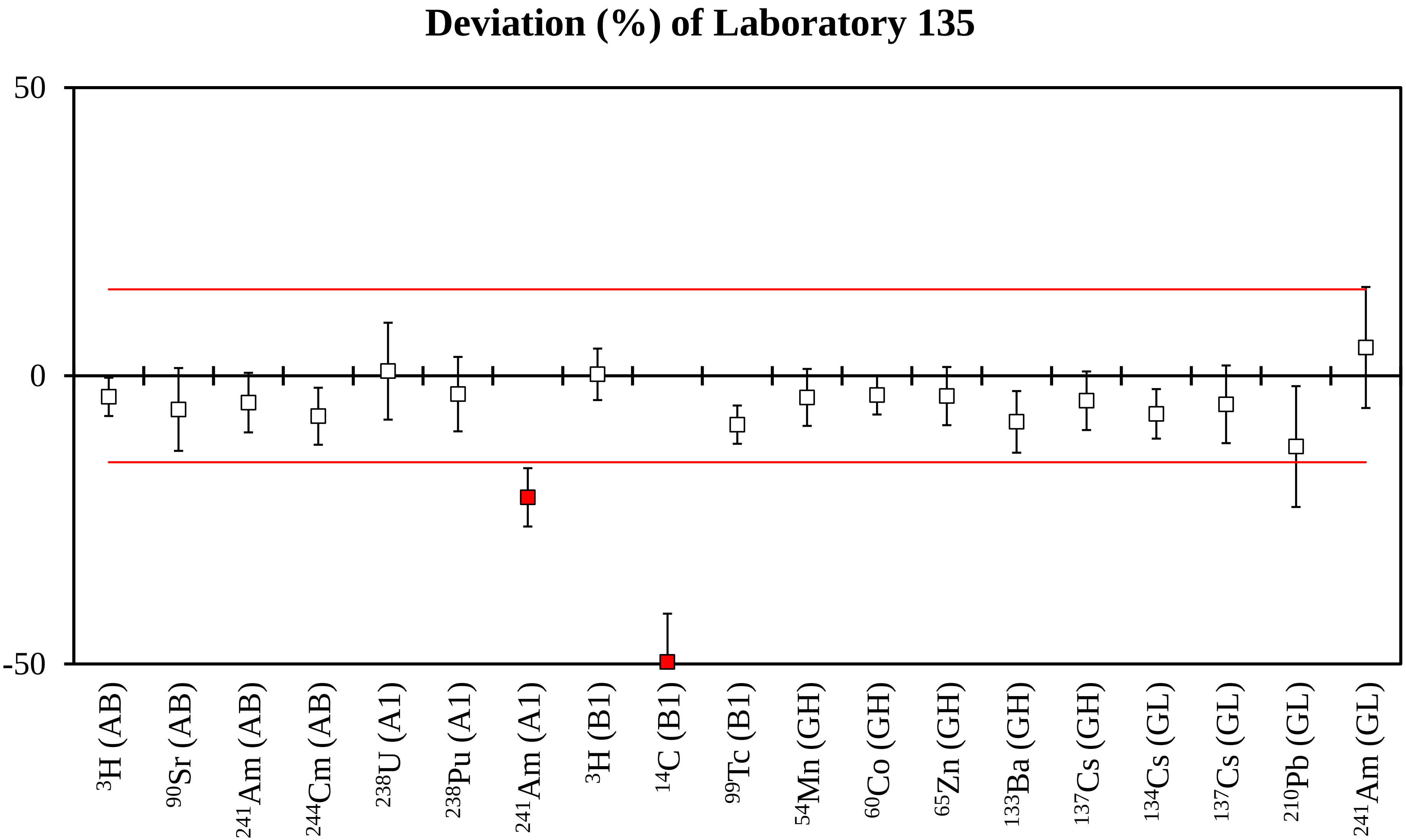
Radionuclide	Laboratory 120	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	13.7 ± 0.3	14.22 ± 0.15	−3.7	−1.55	−0.63
^{90}Sr (AB)	6.41 ± 0.67	6.266 ± 0.016	2.3	0.21	0.39
^{241}Am (AB)	7.53 ± 0.47	7.761 ± 0.031	−3.0	−0.49	−0.51
^{244}Cm (AB)	4.59 ± 0.29	5.0547 ± 0.0073	−9.2	−1.60	−1.58
^{238}U (A1)	4.06 ± 0.34	4.861 ± 0.083	−16.5	−2.29	−2.83
^{238}Pu (A1)	2.51 ± 0.14	2.1690 ± 0.0054	15.7	2.43	2.70
^{241}Am (A1)	15.8 ± 1.0	15.841 ± 0.067	−0.3	−0.04	−0.04
^{3}H (B1)	0.582 ± 0.011	0.5885 ± 0.0081	−1.1	−0.48	−0.19
^{14}C (B1)	0.5150 ± 0.0043	0.4769 ± 0.0044	8.0	6.19	1.37
^{54}Mn (GH)	5.19 ± 0.13	5.091 ± 0.029	1.9	0.74	0.33
^{60}Co (GH)	2.42 ± 0.06	2.3900 ± 0.0095	1.3	0.49	0.22
^{65}Zn (GH)	2.69 ± 0.16	2.612 ± 0.023	3.0	0.48	0.51
^{133}Ba (GH)	27.90 ± 0.80	28.26 ± 0.20	−1.3	−0.44	−0.22
^{137}Cs (GH)	40.20 ± 0.80	39.72 ± 0.29	1.2	0.56	0.21
^{134}Cs (GL)	10.7 ± 0.3	10.600 ± 0.076	0.9	0.32	0.16
^{137}Cs (GL)	6.90 ± 0.26	6.733 ± 0.061	2.5	0.63	0.43
^{241}Am (GL)	23.3 ± 1.3	23.83 ± 0.10	−2.2	−0.41	−0.38


Deviation (%) of Laboratory 126
50
0
-50
^{54}Mn (GH)
^{60}Co (GH)
^{65}Zn (GH)
^{133}Ba (GH)
^{137}Cs (GH)
^{134}Cs (GL)
^{137}Cs (GL)
^{210}Pb (GL)
^{241}Am (GL)

Radionuclide	Laboratory 126	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{54}Mn (GH)	5.15 ± 0.41	5.091 ± 0.029	1.2	0.14	0.20
^{60}Co (GH)	2.36 ± 0.19	2.3900 ± 0.0095	−1.3	−0.16	−0.22
^{65}Zn (GH)	2.69 ± 0.22	2.612 ± 0.023	3.0	0.35	0.51
^{133}Ba (GH)	27.6 ± 4.4	28.26 ± 0.20	−2.3	−0.15	−0.40
^{137}Cs (GH)	39.8 ± 3.2	39.72 ± 0.29	0.2	0.02	0.03
^{134}Cs (GL)	7.4 ± 1.2	10.600 ± 0.076	−30.2	−2.66	−5.18
^{137}Cs (GL)	6.99 ± 0.56	6.733 ± 0.061	3.8	0.46	0.66
^{210}Pb (GL)	21.8 ± 3.5	23.94 ± 0.25	−8.9	−0.61	−1.54
^{241}Am (GL)	25.6 ± 2.0	23.83 ± 0.10	7.4	0.88	1.28

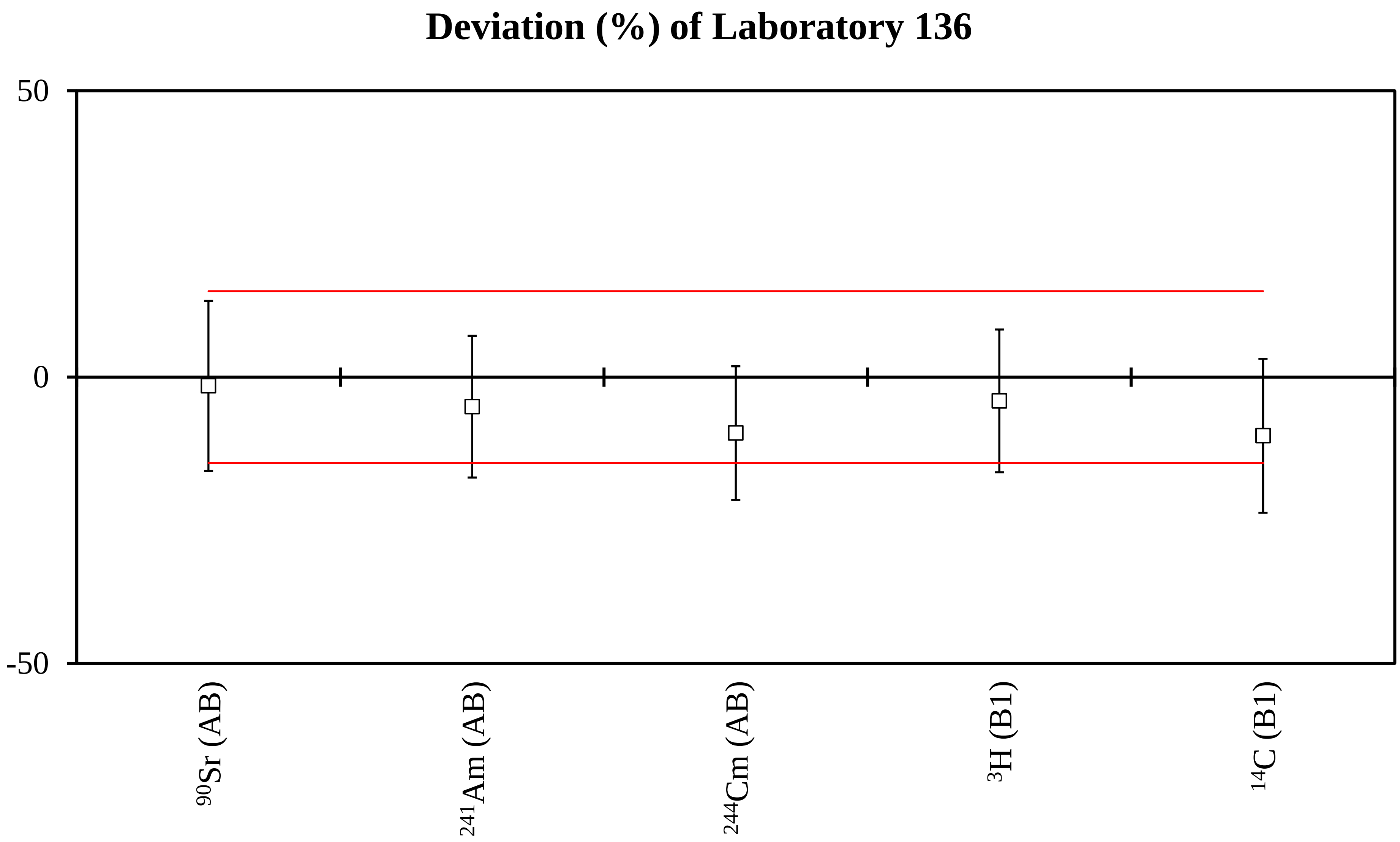

Deviation (%) of Laboratory 129
50
0
-50
238U (A1)
238Pu (A1)
241Am (A1)

Radionuclide	Laboratory 129	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{238}U (A1)	3.47 ± 0.32	4.861 ± 0.083	−28.6	−4.21	−4.91
^{238}Pu (A1)	1.47 ± 0.12	2.1690 ± 0.0054	−32.2	−5.82	−5.53
^{241}Am (A1)	9.36 ± 0.77	15.841 ± 0.067	−40.9	−8.39	−7.03

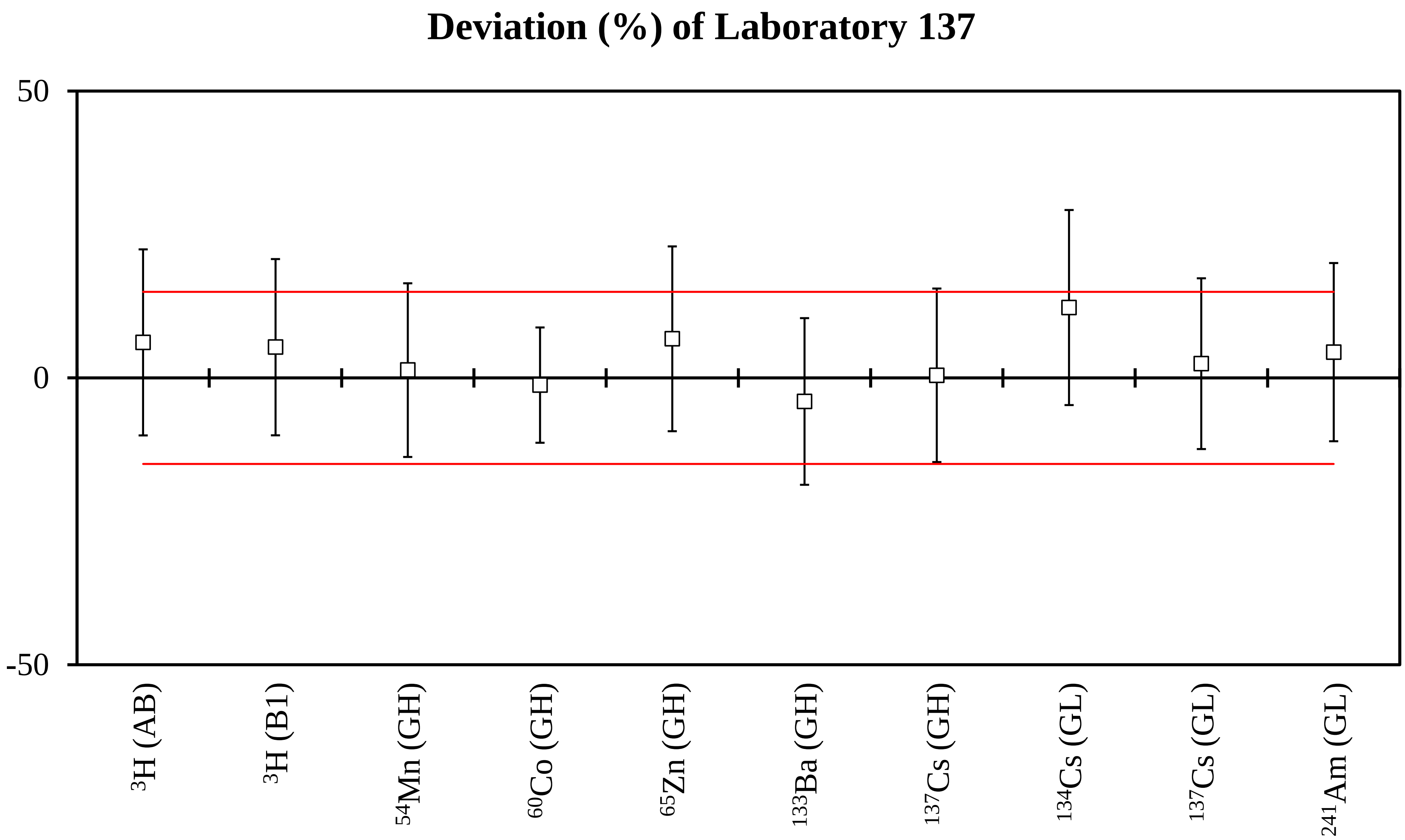


Deviation (%) of Laboratory 135
50
0
-50
3H (AB)
90Sr (AB)
241Am (AB)
244Cm (AB)
238U (A1)
238Pu (A1)
241Am (A1)
3H (B1)
14C (B1)
99Tc (B1)
54Mn (GH)
60Co (GH)
65Zn (GH)
133Ba (GH)
137Cs (GH)
134Cs (GL)
137Cs (GL)
210Pb (GL)
241Am (GL)

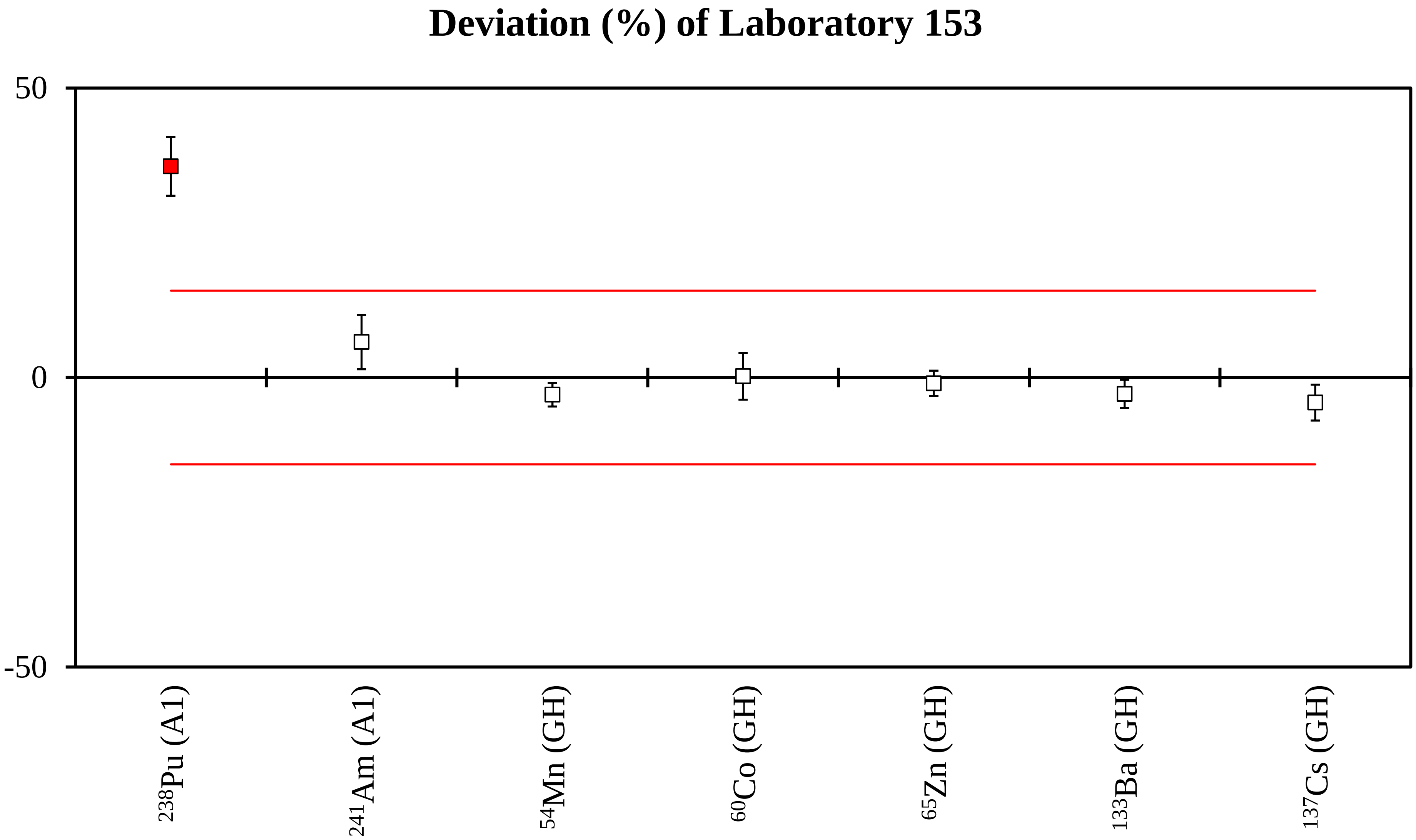
Radionuclide	Laboratory 135	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	13.70 ± 0.45	14.22 ± 0.15	−3.7	−1.10	−0.63
^{90}Sr (AB)	5.90 ± 0.45	6.266 ± 0.016	−5.8	−0.81	−1.00
^{241}Am (AB)	7.40 ± 0.40	7.761 ± 0.031	−4.7	−0.90	−0.80
^{244}Cm (AB)	4.70 ± 0.25	5.0547 ± 0.0073	−7.0	−1.42	−1.21
^{238}U (A1)	4.90 ± 0.40	4.861 ± 0.083	0.8	0.10	0.14
^{238}Pu (A1)	2.10 ± 0.14	2.1690 ± 0.0054	−3.2	−0.49	−0.55
^{241}Am (A1)	12.50 ± 0.80	15.841 ± 0.067	−21.1	−4.16	−3.62
^{3}H (B1)	0.590 ± 0.025	0.5885 ± 0.0081	0.3	0.06	0.04
^{14}C (B1)	0.240 ± 0.040	0.4769 ± 0.0044	−49.7	−5.89	−8.53
^{99}Tc (B1)	0.1900 ± 0.0065	0.2076 ± 0.0025	−8.5	−2.53	−1.46
^{54}Mn (GH)	4.90 ± 0.25	5.091 ± 0.029	−3.8	−0.76	−0.64
^{60}Co (GH)	2.310 ± 0.080	2.3900 ± 0.0095	−3.3	−0.99	−0.57
^{65}Zn (GH)	2.52 ± 0.13	2.612 ± 0.023	−3.5	−0.70	−0.60
^{133}Ba (GH)	26.0 ± 1.5	28.26 ± 0.20	−8.0	−1.49	−1.37
^{137}Cs (GH)	38.0 ± 2.0	39.72 ± 0.29	−4.3	−0.85	−0.74
^{134}Cs (GL)	9.90 ± 0.45	10.600 ± 0.076	−6.6	−1.53	−1.13
^{137}Cs (GL)	6.40 ± 0.45	6.733 ± 0.061	−4.9	−0.73	−0.85
^{210}Pb (GL)	21.0 ± 2.5	23.94 ± 0.25	−12.3	−1.17	−2.11
^{241}Am (GL)	25.0 ± 2.5	23.83 ± 0.10	4.9	0.47	0.84


Deviation (%) of Laboratory 136
50
0
-50
^{90}Sr (AB)
^{241}Am (AB)
^{244}Cm (AB)
^{3}H (B1)
^{14}C (B1)

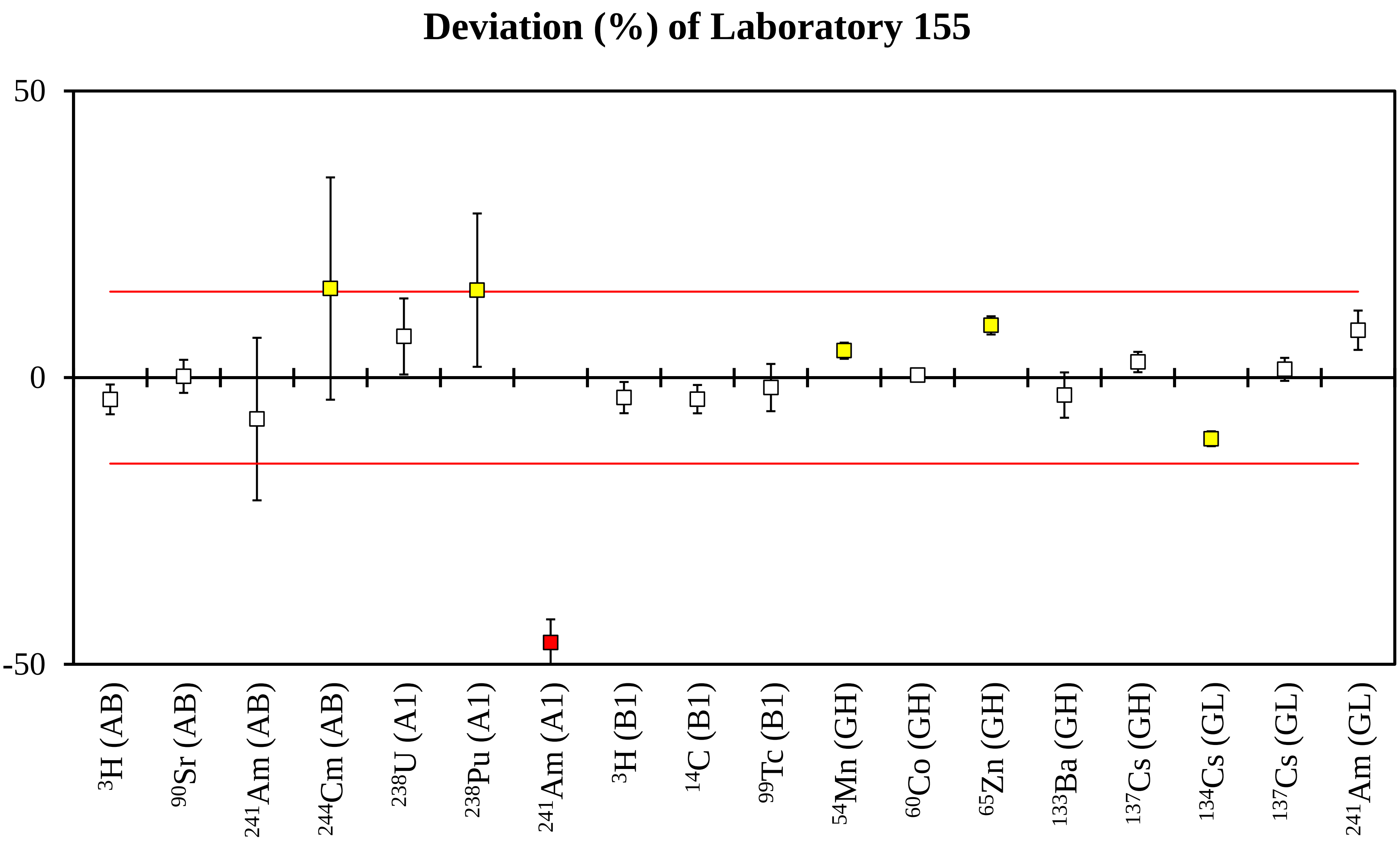
Radionuclide	Laboratory 136	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{90}Sr (AB)	6.17 ± 0.93	6.266 ± 0.016	−1.5	−0.10	−0.26
^{241}Am (AB)	7.36 ± 0.96	7.761 ± 0.031	−5.2	−0.42	−0.89
^{244}Cm (AB)	4.56 ± 0.59	5.0547 ± 0.0073	−9.8	−0.84	−1.68
^{3}H (B1)	0.564 ± 0.073	0.5885 ± 0.0081	−4.2	−0.33	−0.71
^{14}C (B1)	0.428 ± 0.064	0.4769 ± 0.0044	−10.3	−0.76	−1.76


Deviation (%) of Laboratory 137
50
0
-50
3H (AB)
3H (B1)
54Mn (GH)
60Co (GH)
65Zn (GH)
133Ba (GH)
137Cs (GH)
134Cs (GL)
137Cs (GL)
241Am (GL)

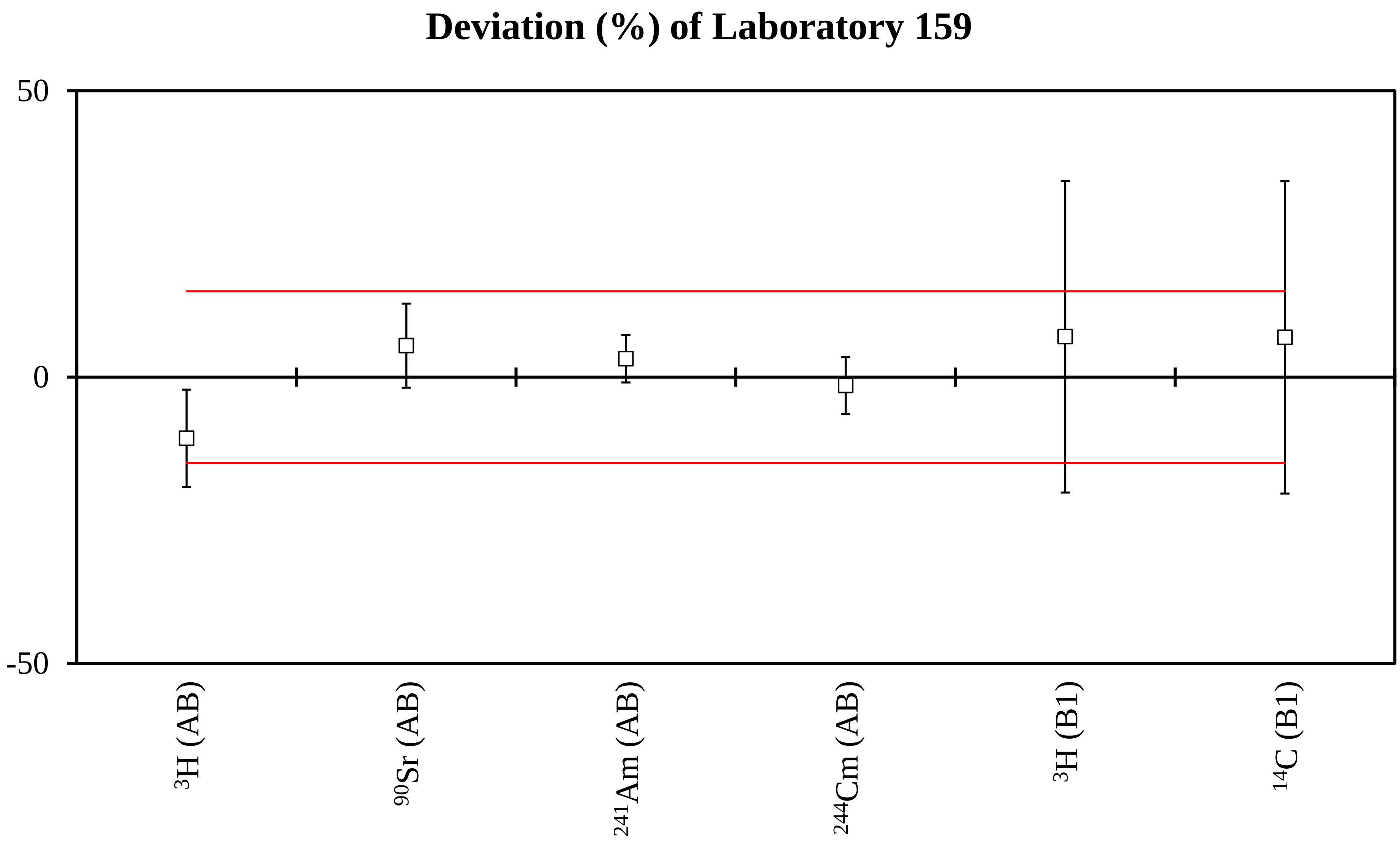
Radionuclide	Laboratory 137	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	15.1 ± 2.3	14.22 ± 0.15	6.2	0.38	1.06
^{3}H (B1)	0.62 ± 0.09	0.5885 ± 0.0081	5.4	0.35	0.92
^{54}Mn (GH)	5.16 ± 0.77	5.091 ± 0.029	1.4	0.09	0.23
^{60}Co (GH)	2.36 ± 0.24	2.3900 ± 0.0095	−1.3	−0.12	−0.22
^{65}Zn (GH)	2.79 ± 0.42	2.612 ± 0.023	6.8	0.42	1.17
^{133}Ba (GH)	27.1 ± 4.1	28.26 ± 0.20	−4.1	−0.28	−0.70
^{137}Cs (GH)	39.9 ± 6.0	39.72 ± 0.29	0.5	0.03	0.08
^{134}Cs (GL)	11.9 ± 1.8	10.600 ± 0.076	12.3	0.72	2.11
^{137}Cs (GL)	6.9 ± 1.0	6.733 ± 0.061	2.5	0.17	0.43
^{241}Am (GL)	24.9 ± 3.7	23.83 ± 0.10	4.5	0.29	0.77


Deviation (%) of Laboratory 153
50
0
-50
238Pu (A1)
241Am (A1)
54Mn (GH)
60Co (GH)
65Zn (GH)
133Ba (GH)
137Cs (GH)

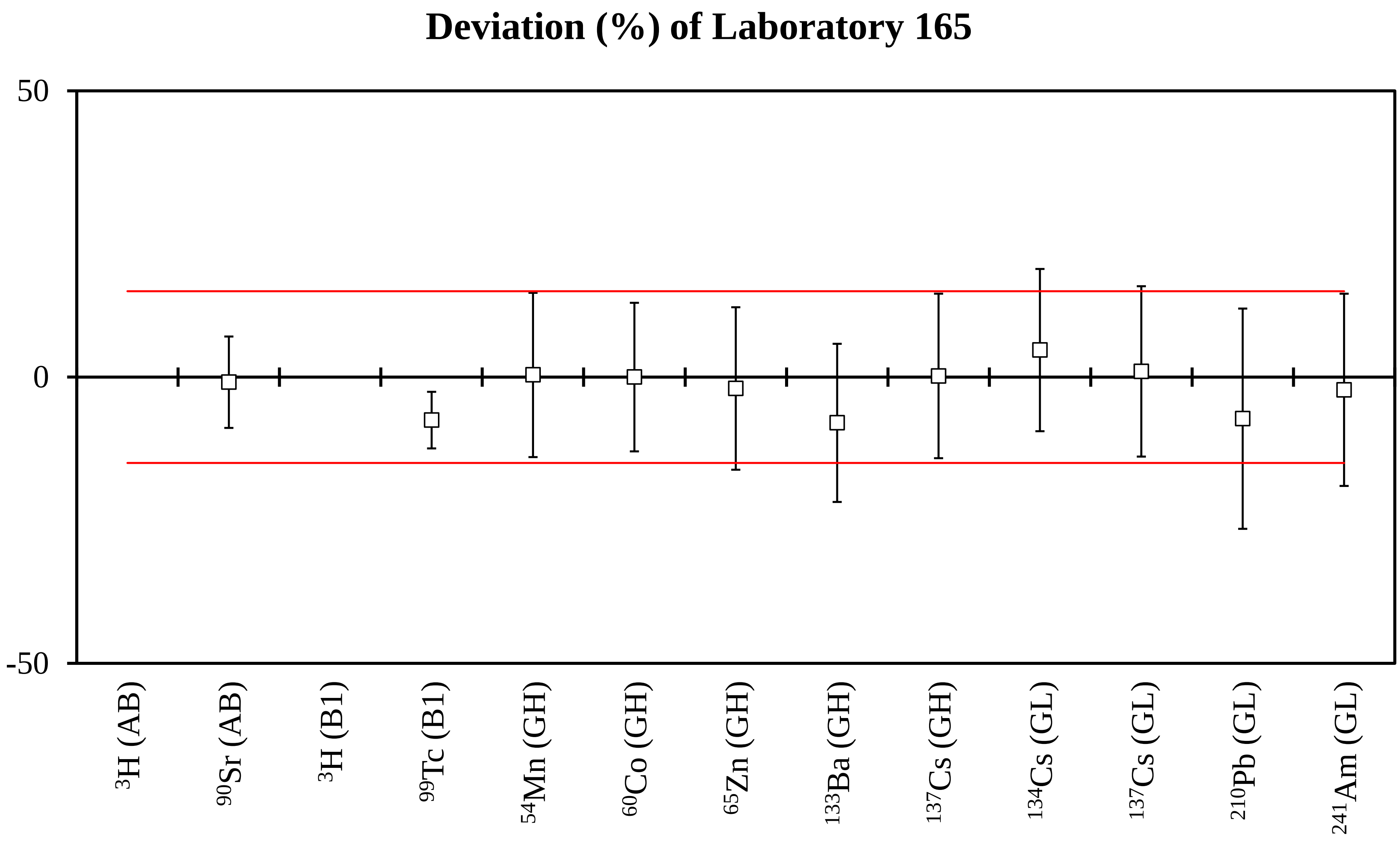
Radionuclide	Laboratory 153	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{238}Pu (A1)	2.96 ± 0.11	2.1690 ± 0.0054	36.5	7.18	6.26
^{241}Am (A1)	16.81 ± 0.74	15.841 ± 0.067	6.1	1.30	1.05
^{54}Mn (GH)	4.939 ± 0.100	5.091 ± 0.029	−3.0	−1.45	−0.51
^{60}Co (GH)	2.395 ± 0.096	2.3900 ± 0.0095	0.2	0.05	0.04
^{65}Zn (GH)	2.586 ± 0.052	2.612 ± 0.023	−1.0	−0.46	−0.17
^{133}Ba (GH)	27.46 ± 0.66	28.26 ± 0.20	−2.8	−1.16	−0.49
^{137}Cs (GH)	38.0 ± 1.2	39.72 ± 0.29	−4.3	−1.39	−0.74


Deviation (%) of Laboratory 155
50
0
-50
3H (AB)
90Sr (AB)
241Am (AB)
244Cm (AB)
238U (A1)
238Pu (A1)
241Am (A1)
3H (B1)
14C (B1)
99Tc (B1)
54Mn (GH)
60Co (GH)
65Zn (GH)
133Ba (GH)
137Cs (GH)
134Cs (GL)
137Cs (GL)
241Am (GL)

Radionuclide	Laboratory 155	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	13.68 ± 0.34	14.22 ± 0.15	−3.8	−1.45	−0.65
^{90}Sr (AB)	6.28 ± 0.18	6.266 ± 0.016	0.2	0.08	0.04
^{241}Am (AB)	7.2 ± 1.1	7.761 ± 0.031	−7.2	−0.51	−1.24
^{244}Cm (AB)	5.84 ± 0.98	5.0547 ± 0.0073	15.5	0.80	2.67
^{238}U (A1)	5.21 ± 0.31	4.861 ± 0.083	7.2	1.09	1.23
^{238}Pu (A1)	2.50 ± 0.29	2.1690 ± 0.0054	15.3	1.14	2.62
^{241}Am (A1)	8.52 ± 0.64	15.841 ± 0.067	−46.2	−11.38	−7.94
^{3}H (B1)	0.568 ± 0.014	0.5885 ± 0.0081	−3.5	−1.27	−0.60
^{14}C (B1)	0.459 ± 0.011	0.4769 ± 0.0044	−3.8	−1.51	−0.64
^{99}Tc (B1)	0.2040 ± 0.0082	0.2076 ± 0.0025	−1.7	−0.42	−0.30
^{54}Mn (GH)	5.330 ± 0.065	5.091 ± 0.029	4.7	3.36	0.81
^{60}Co (GH)	2.400 ± 0.021	2.3900 ± 0.0095	0.4	0.43	0.07
^{65}Zn (GH)	2.850 ± 0.033	2.612 ± 0.023	9.1	5.92	1.56
^{133}Ba (GH)	27.4 ± 1.1	28.26 ± 0.20	−3.0	−0.77	−0.52
^{137}Cs (GH)	40.80 ± 0.64	39.72 ± 0.29	2.7	1.54	0.47
^{134}Cs (GL)	9.47 ± 0.12	10.600 ± 0.076	−10.7	−7.96	−1.83
^{137}Cs (GL)	6.83 ± 0.12	6.733 ± 0.061	1.4	0.72	0.25
^{241}Am (GL)	25.80 ± 0.81	23.83 ± 0.10	8.3	2.41	1.42

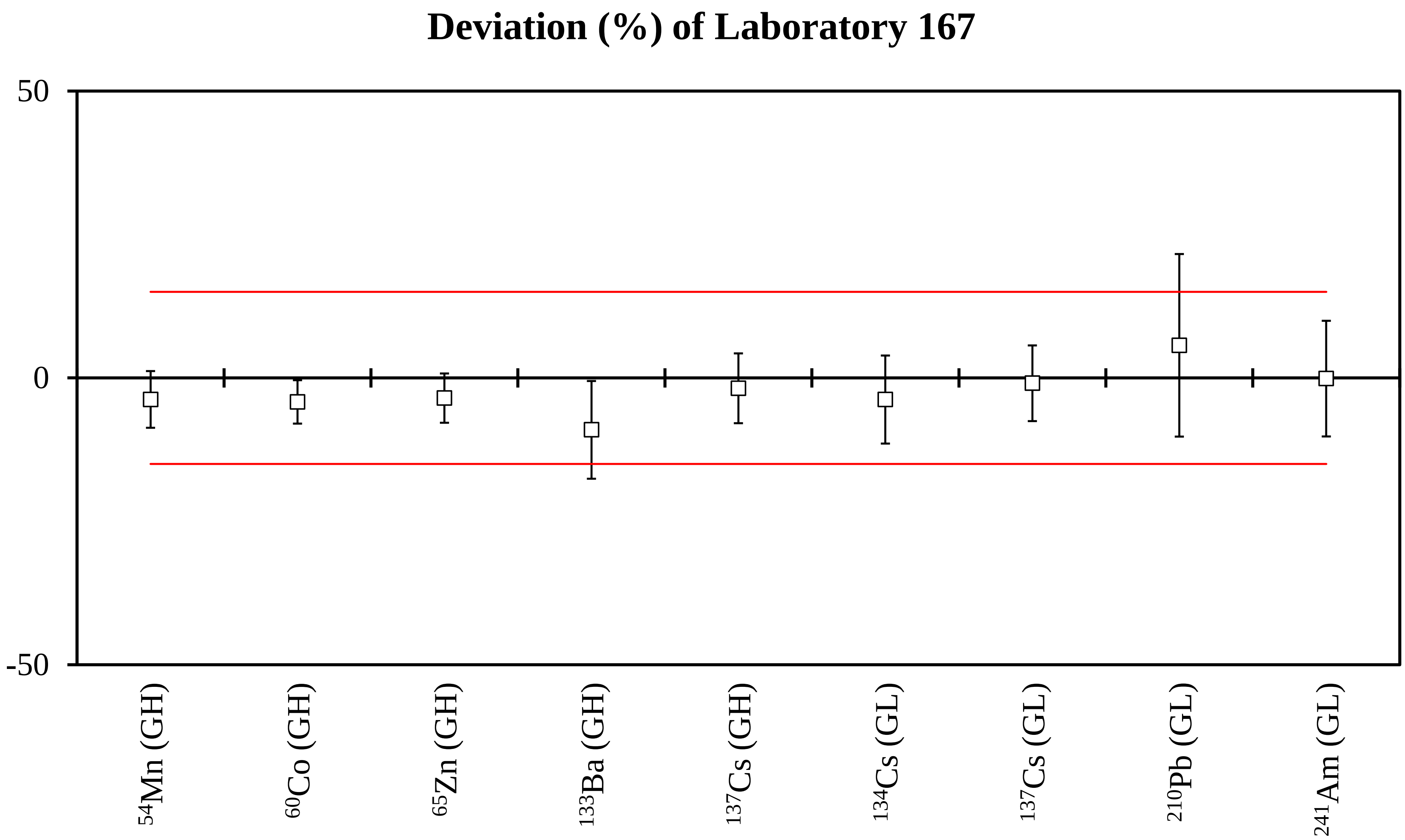

Deviation (%) of Laboratory 159
50
0
-50
^{3}H (AB)
^{90}Sr (AB)
^{241}Am (AB)
^{244}Cm (AB)
^{3}H (B1)
^{14}C (B1)

Radionuclide	Laboratory 159	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	12.7 ± 1.2	14.22 ± 0.15	−10.7	−1.26	−1.84
^{90}Sr (AB)	6.61 ± 0.46	6.266 ± 0.016	5.5	0.75	0.94
^{241}Am (AB)	8.01 ± 0.32	7.761 ± 0.031	3.2	0.77	0.55
^{244}Cm (AB)	4.98 ± 0.25	5.0547 ± 0.0073	−1.5	−0.30	−0.25
^{3}H (B1)	0.63 ± 0.16	0.5885 ± 0.0081	7.1	0.26	1.21
^{14}C (B1)	0.51 ± 0.13	0.4769 ± 0.0044	6.9	0.25	1.19

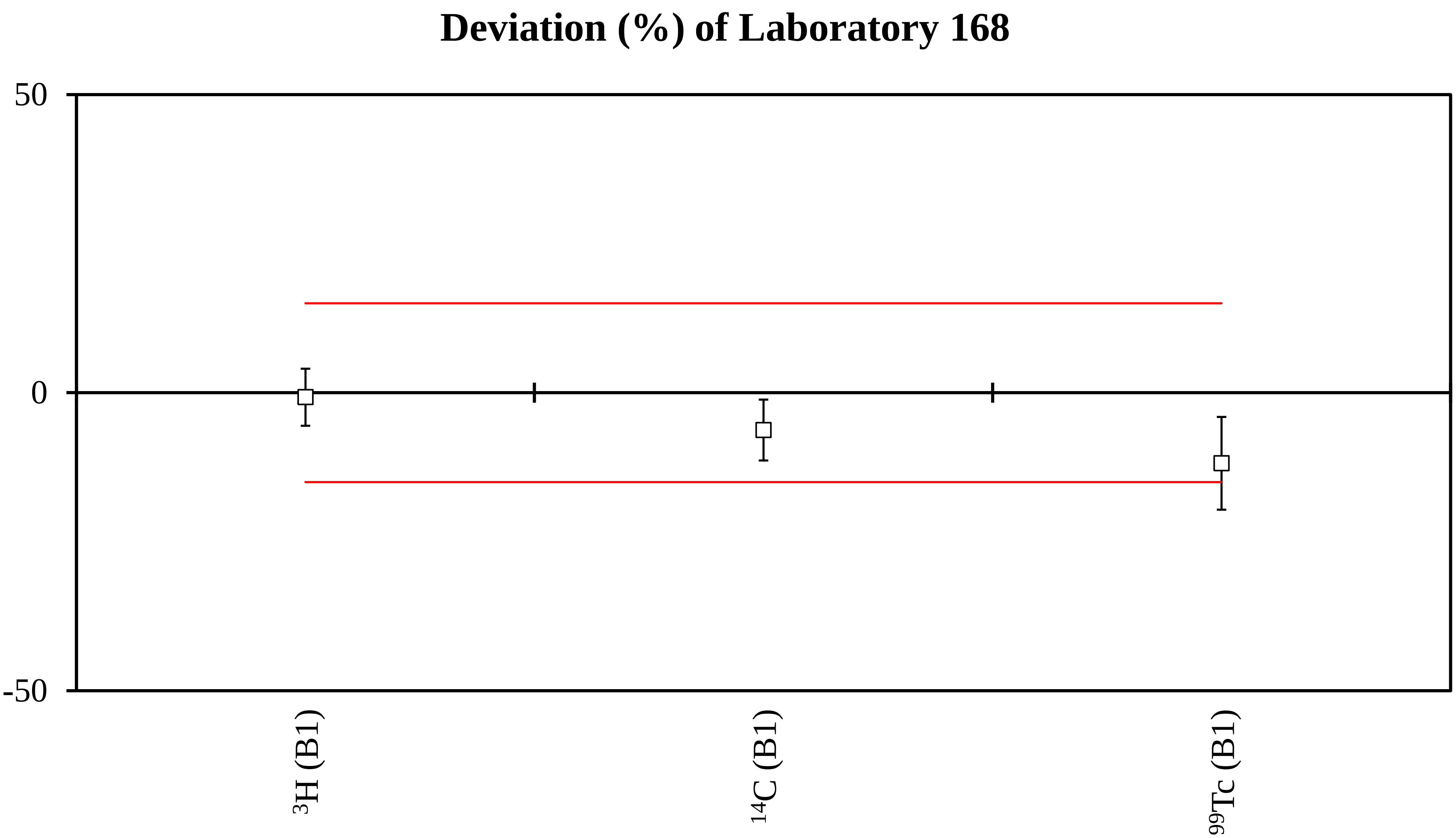

Deviation (%) of Laboratory 165
50
0
-50
3H (AB)
90Sr (AB)
3H (B1)
99Tc (B1)
54Mn (GH)
60Co (GH)
65Zn (GH)
133Ba (GH)
137Cs (GH)
134Cs (GL)
137Cs (GL)
210Pb (GL)
241Am (GL)

Radionuclide	Laboratory 165	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)[3]	0.556 ± 0.023	14.22 ± 0.15	−96.1	−90.04	−16.50
^{90}Sr (AB)	6.21 ± 0.50	6.266 ± 0.016	−0.9	−0.11	−0.15
^{3}H (B1)	0.0899 ± 0.0038	0.5885 ± 0.0081	−84.7	−55.73	−14.55
^{99}Tc (B1)	0.192 ± 0.010	0.2076 ± 0.0025	−7.5	−1.51	−1.29
^{54}Mn (GH)	5.11 ± 0.73	5.091 ± 0.029	0.4	0.03	0.06
^{60}Co (GH)	2.39 ± 0.31	2.3900 ± 0.0095	0.0	0.00	0.00
^{65}Zn (GH)	2.56 ± 0.37	2.612 ± 0.023	−2.0	−0.14	−0.34
^{133}Ba (GH)	26.0 ± 3.9	28.26 ± 0.20	−8.0	−0.58	−1.37
^{137}Cs (GH)	39.8 ± 5.7	39.72 ± 0.29	0.2	0.01	0.03
^{134}Cs (GL)	11.1 ± 1.5	10.600 ± 0.076	4.7	0.33	0.81
^{137}Cs (GL)	6.8 ± 1.0	6.733 ± 0.061	1.0	0.07	0.17
^{210}Pb (GL)	22.2 ± 4.6	23.94 ± 0.25	−7.3	−0.38	−1.25
^{241}Am (GL)	23.3 ± 4.0	23.83 ± 0.10	−2.2	−0.13	−0.38

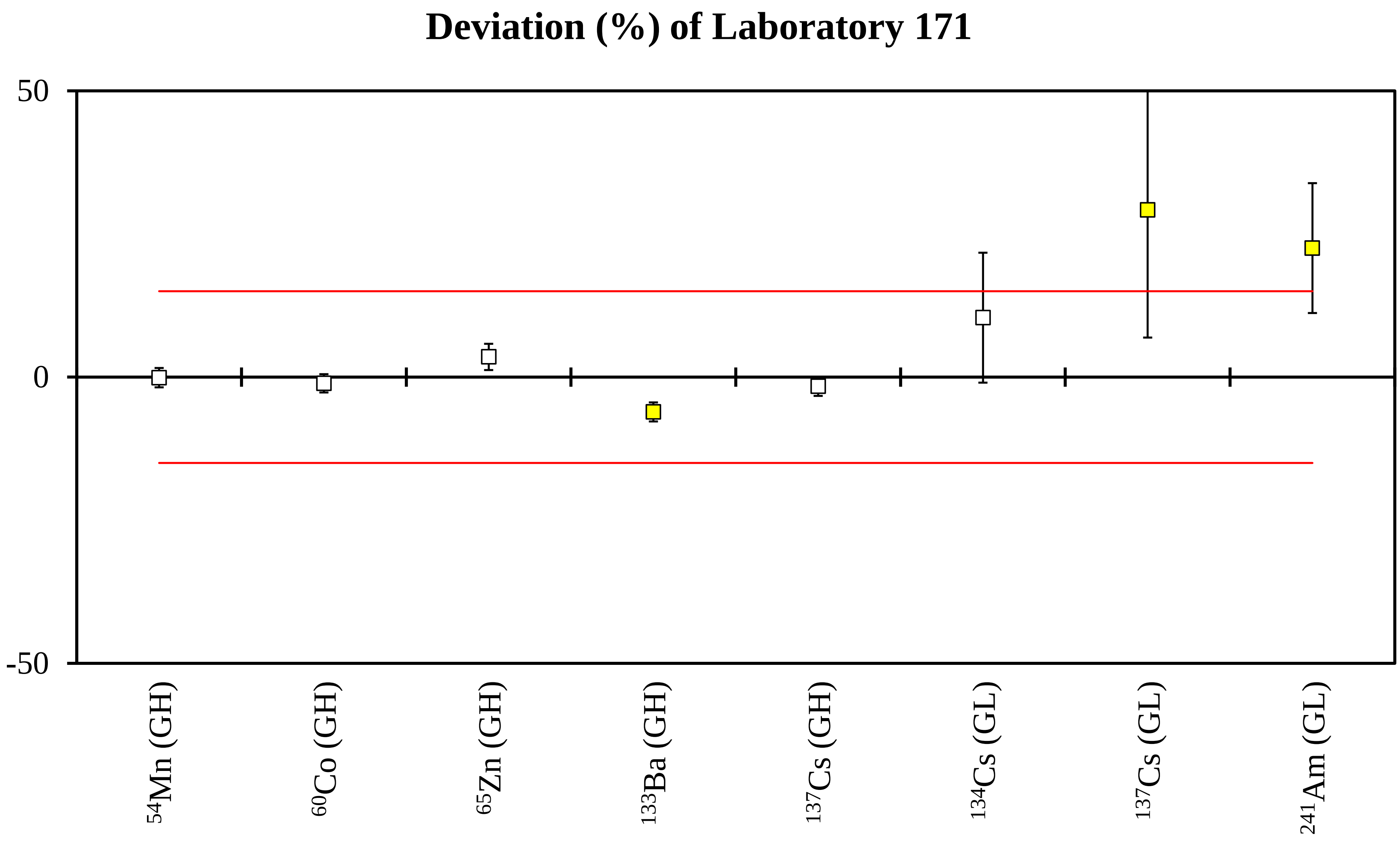
[3]Please note that participant stated a transcription error was made during the reporting of the ^{3}H results for both the AB and B1 sample types.


Deviation (%) of Laboratory 167
50
0
-50
54Mn (GH)
60Co (GH)
65Zn (GH)
133Ba (GH)
137Cs (GH)
134Cs (GL)
137Cs (GL)
210Pb (GL)
241Am (GL)

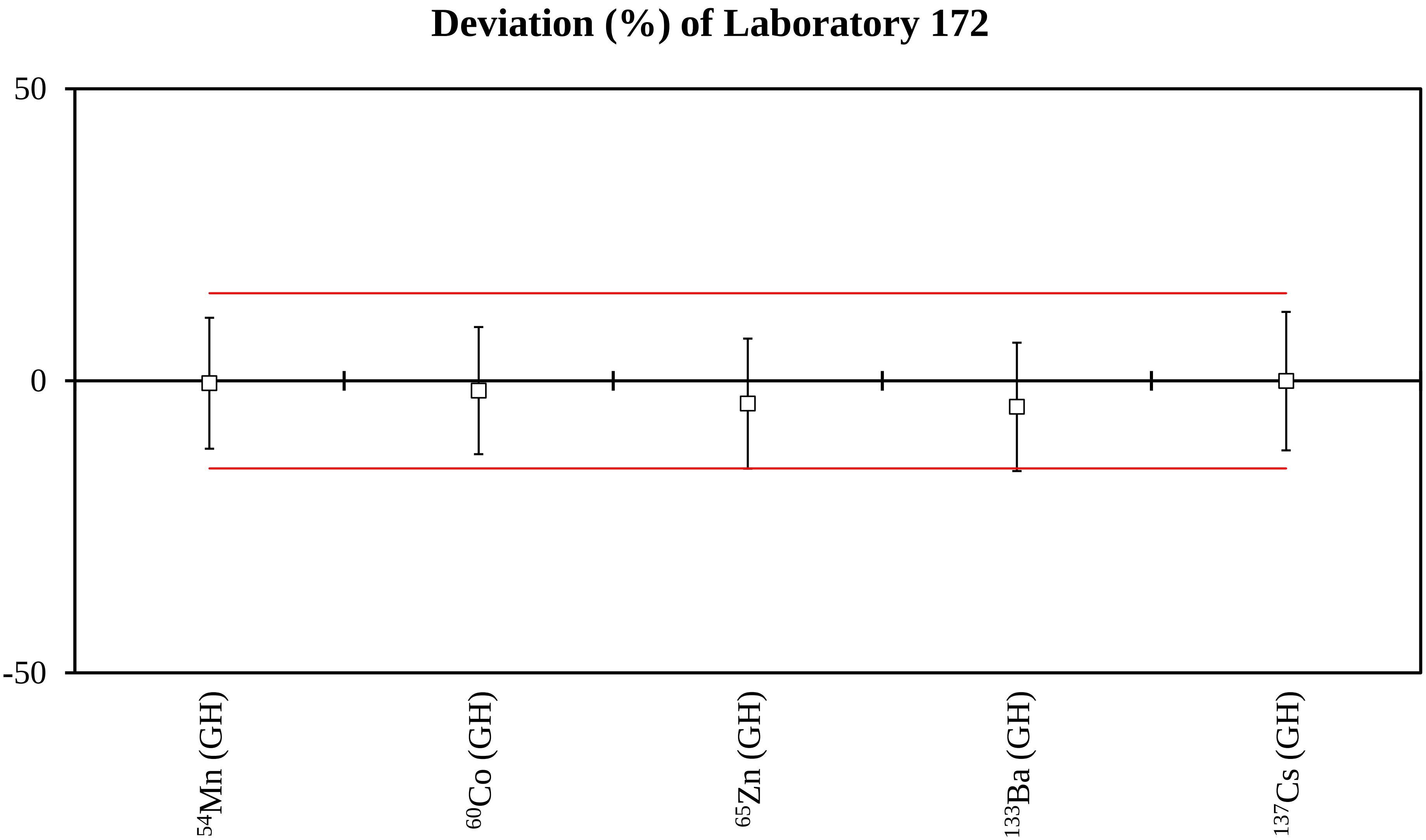
Radionuclide	Laboratory 167	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{54}Mn (GH)	4.90 ± 0.25	5.091 ± 0.029	−3.8	−0.76	−0.64
^{60}Co (GH)	2.29 ± 0.09	2.3900 ± 0.0095	−4.2	−1.10	−0.72
^{65}Zn (GH)	2.52 ± 0.11	2.612 ± 0.023	−3.5	−0.82	−0.60
^{133}Ba (GH)	25.7 ± 2.4	28.26 ± 0.20	−9.1	−1.06	−1.56
^{137}Cs (GH)	39.0 ± 2.4	39.72 ± 0.29	−1.8	−0.30	−0.31
^{134}Cs (GL)	10.20 ± 0.81	10.600 ± 0.076	−3.8	−0.49	−0.65
^{137}Cs (GL)	6.67 ± 0.44	6.733 ± 0.061	−0.9	−0.14	−0.16
^{210}Pb (GL)	25.3 ± 3.8	23.94 ± 0.25	5.7	0.36	0.98
^{241}Am (GL)	23.8 ± 2.4	23.83 ± 0.10	−0.1	−0.01	−0.02


Deviation (%) of Laboratory 168
50
0
-50
3H (B1)
14C (B1)
99Tc (B1)

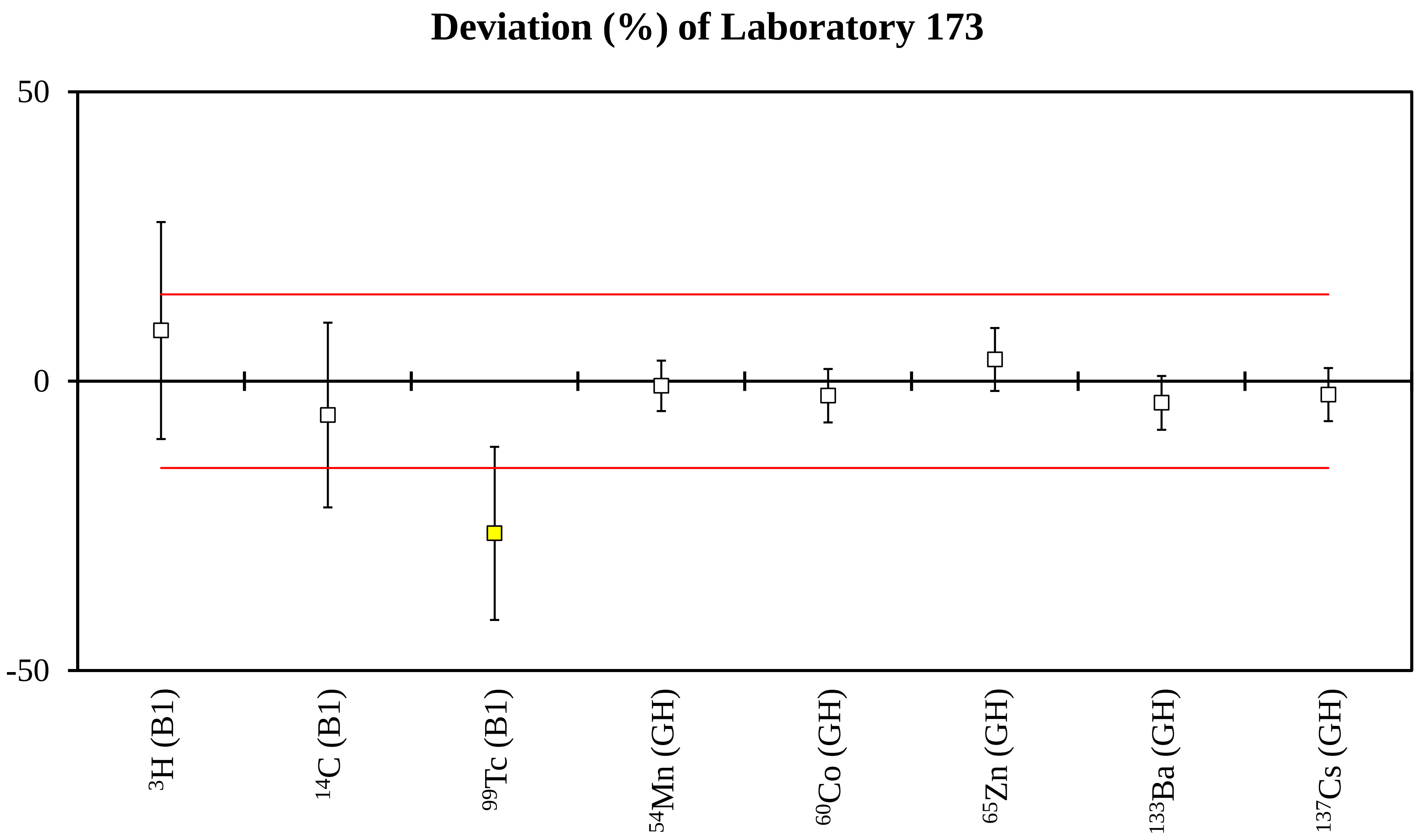
Radionuclide	Laboratory 168	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (B1)	0.584 ± 0.027	0.5885 ± 0.0081	−0.8	−0.16	−0.13
^{14}C (B1)	0.447 ± 0.024	0.4769 ± 0.0044	−6.3	−1.23	−1.08
^{99}Tc (B1)	0.183 ± 0.016	0.2076 ± 0.0025	−11.8	−1.52	−2.03


Deviation (%) of Laboratory 171
50
0
-50
^{54}Mn (GH)
^{60}Co (GH)
^{65}Zn (GH)
^{133}Ba (GH)
^{137}Cs (GH)
^{134}Cs (GL)
^{137}Cs (GL)
^{241}Am (GL)

Radionuclide	Laboratory 171	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{54}Mn (GH)	5.086 ± 0.081	5.091 ± 0.029	−0.1	−0.06	−0.02
^{60}Co (GH)	2.364 ± 0.037	2.3900 ± 0.0095	−1.1	−0.68	−0.19
^{65}Zn (GH)	2.704 ± 0.055	2.612 ± 0.023	3.5	1.54	0.60
^{133}Ba (GH)	26.54 ± 0.43	28.26 ± 0.20	−6.1	−3.63	−1.05
^{137}Cs (GH)	39.08 ± 0.60	39.72 ± 0.29	−1.6	−0.96	−0.28
^{134}Cs (GL)	11.7 ± 1.2	10.600 ± 0.076	10.4	0.91	1.78
^{137}Cs (GL)	8.7 ± 1.5	6.733 ± 0.061	29.2	1.31	5.02
^{241}Am (GL)	29.2 ± 2.7	23.83 ± 0.10	22.5	1.99	3.87

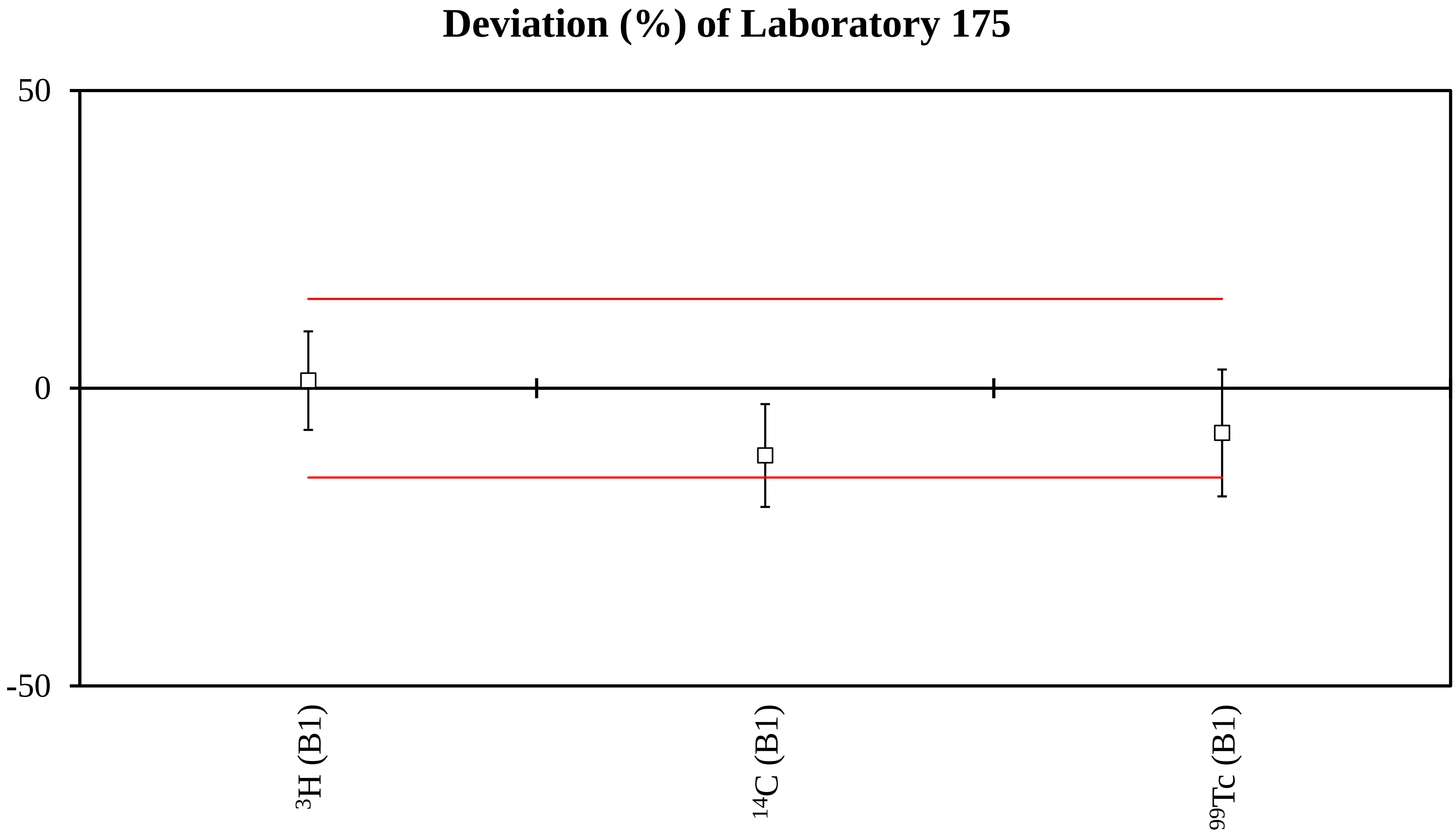

Deviation (%) of Laboratory 172
50
0
-50
54Mn (GH)
60Co (GH)
65Zn (GH)
133Ba (GH)
137Cs (GH)

Radionuclide	Laboratory 172	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{54}Mn (GH)	5.07 ± 0.57	5.091 ± 0.029	−0.4	−0.04	−0.07
^{60}Co (GH)	2.35 ± 0.26	2.3900 ± 0.0095	−1.7	−0.15	−0.29
^{65}Zn (GH)	2.51 ± 0.29	2.612 ± 0.023	−3.9	−0.35	−0.67
^{133}Ba (GH)	27.0 ± 3.1	28.26 ± 0.20	−4.5	−0.41	−0.77
^{137}Cs (GH)	39.7 ± 4.7	39.72 ± 0.29	−0.1	0.00	−0.01

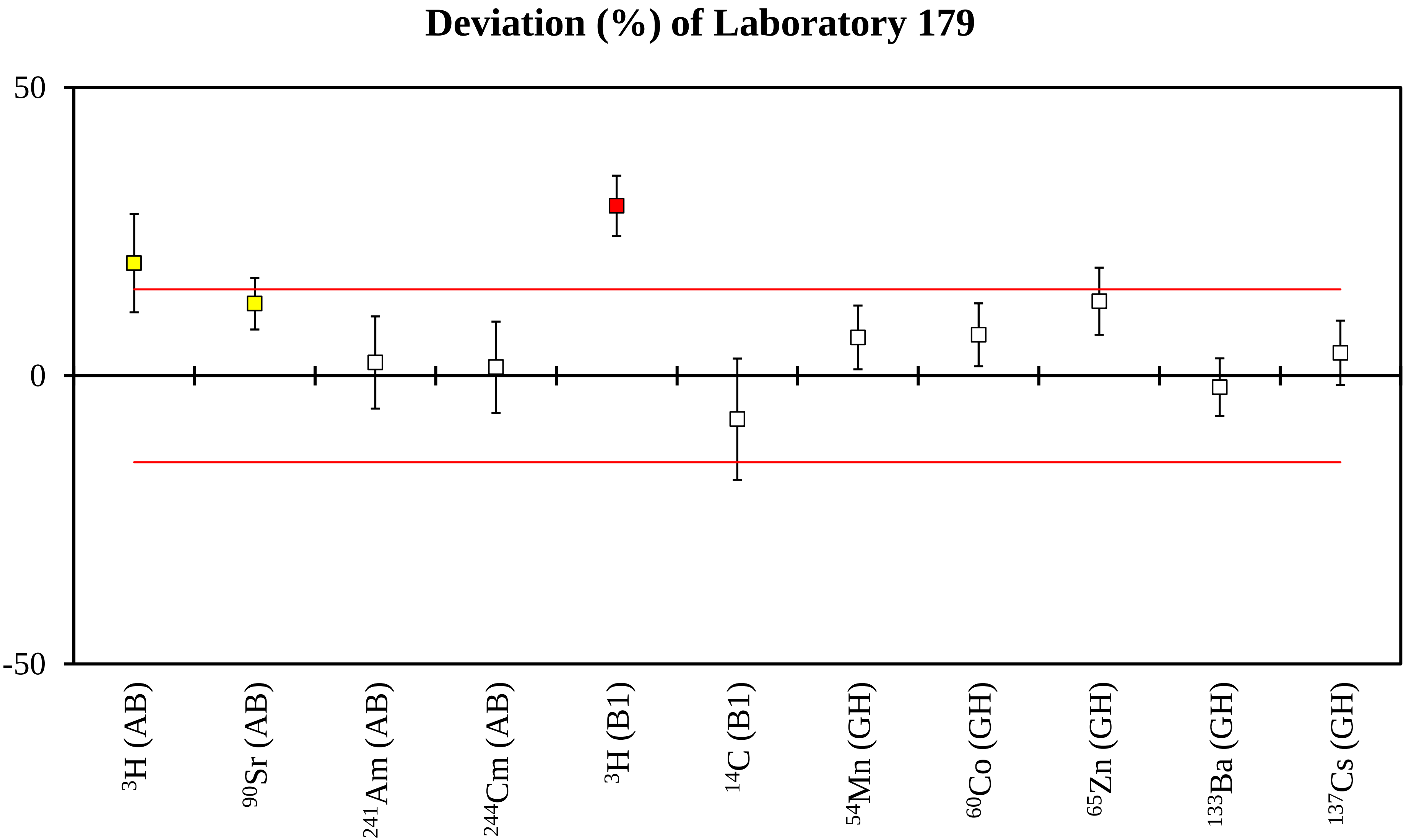


Deviation (%) of Laboratory 173
50
0
-50
3H (B1)
14C (B1)
99Tc (B1)
54Mn (GH)
60Co (GH)
65Zn (GH)
133Ba (GH)
137Cs (GH)

Radionuclide	Laboratory 173	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (B1)	0.64 ± 0.11	0.5885 ± 0.0081	8.8	0.47	1.50
^{14}C (B1)	0.449 ± 0.076	0.4769 ± 0.0044	−5.9	−0.37	−1.00
^{99}Tc (B1)	0.153 ± 0.031	0.2076 ± 0.0025	−26.3	−1.76	−4.52
^{54}Mn (GH)	5.05 ± 0.22	5.091 ± 0.029	−0.8	−0.18	−0.14
^{60}Co (GH)	2.33 ± 0.11	2.3900 ± 0.0095	−2.5	−0.54	−0.43
^{65}Zn (GH)	2.71 ± 0.14	2.612 ± 0.023	3.8	0.69	0.64
^{133}Ba (GH)	27.2 ± 1.3	28.26 ± 0.20	−3.8	−0.81	−0.64
^{137}Cs (GH)	38.8 ± 1.8	39.72 ± 0.29	−2.3	−0.50	−0.40

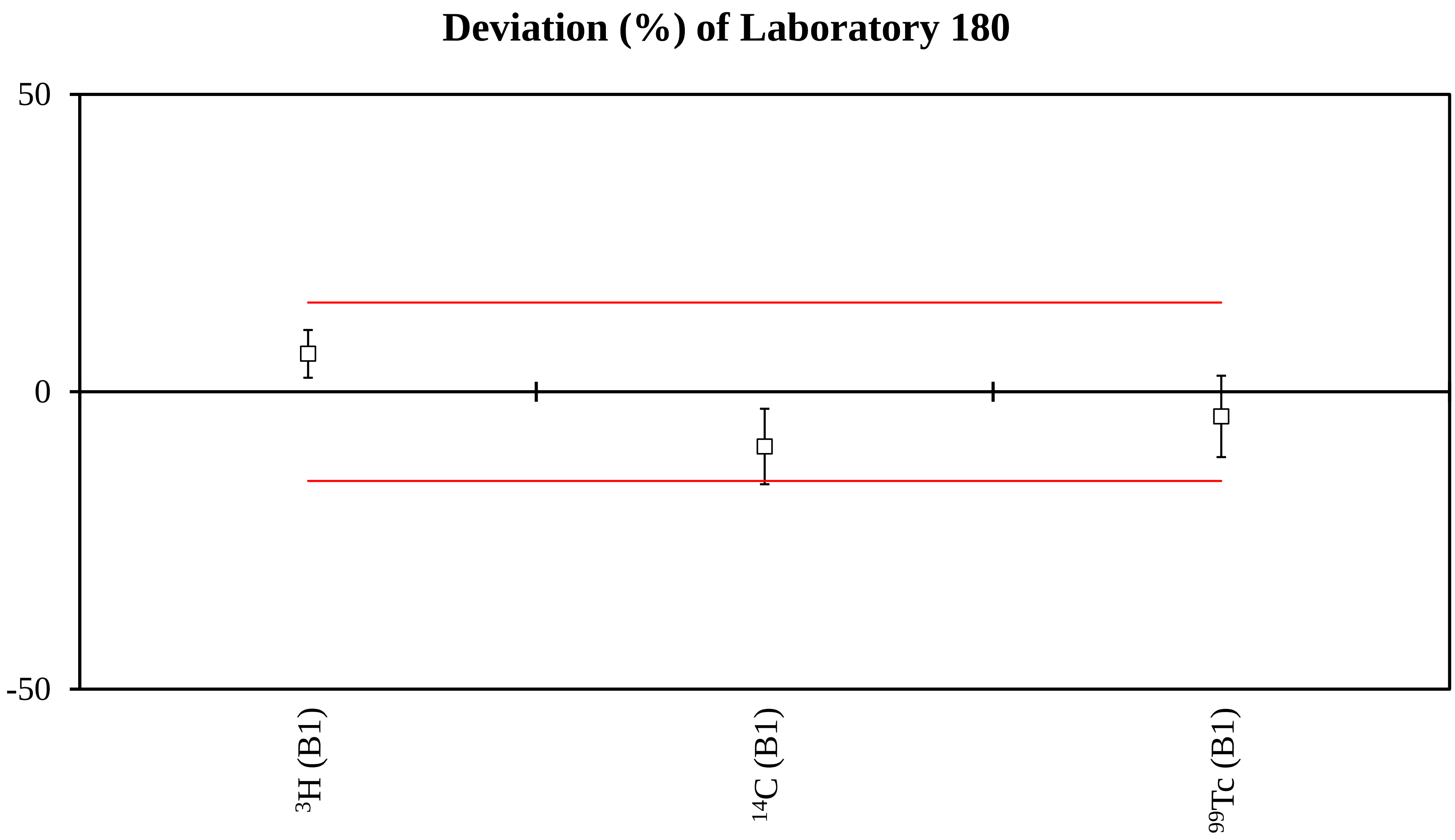

Deviation (%) of Laboratory 175
50
0
-50
3H (B1)
14C (B1)
99Tc (B1)

Radionuclide	Laboratory 175	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (B1)	0.596 ± 0.048	0.5885 ± 0.0081	1.3	0.15	0.22
^{14}C (B1)	0.423 ± 0.041	0.4769 ± 0.0044	−11.3	−1.31	−1.94
^{99}Tc (B1)	0.192 ± 0.022	0.2076 ± 0.0025	−7.5	−0.70	−1.29

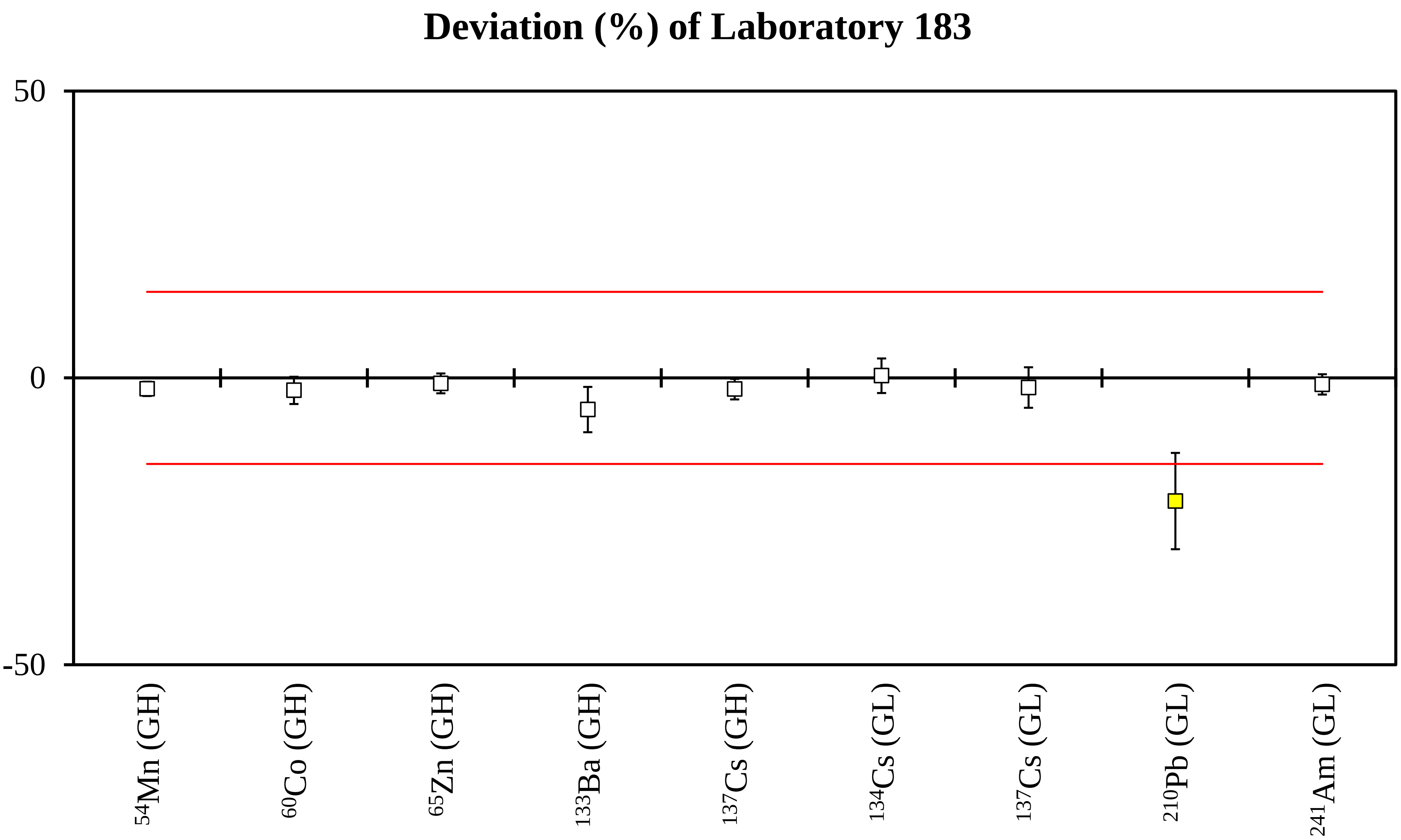

Deviation (%) of Laboratory 179
50
0
-50
3H (AB)
90Sr (AB)
241Am (AB)
244Cm (AB)
3H (B1)
14C (B1)
54Mn (GH)
60Co (GH)
65Zn (GH)
133Ba (GH)
137Cs (GH)

Radionuclide	Laboratory 179	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	17.0 ± 1.2	14.22 ± 0.15	19.5	2.30	3.36
^{90}Sr (AB)	7.05 ± 0.28	6.266 ± 0.016	12.5	2.80	2.15
^{241}Am (AB)	7.94 ± 0.62	7.761 ± 0.031	2.3	0.29	0.40
^{244}Cm (AB)	5.13 ± 0.40	5.0547 ± 0.0073	1.5	0.19	0.26
^{3}H (B1)[4]	0.762 ± 0.029	0.5885 ± 0.0081	29.5	5.76	5.06
^{14}C (B1)	0.441 ± 0.050	0.4769 ± 0.0044	−7.5	−0.72	−1.29
^{54}Mn (GH)	5.43 ± 0.28	5.091 ± 0.029	6.7	1.20	1.14
^{60}Co (GH)	2.56 ± 0.13	2.3900 ± 0.0095	7.1	1.30	1.22
^{65}Zn (GH)	2.95 ± 0.15	2.612 ± 0.023	12.9	2.23	2.22
^{133}Ba (GH)	27.7 ± 1.4	28.26 ± 0.20	−2.0	−0.40	−0.34
^{137}Cs (GH)	41.3 ± 2.2	39.72 ± 0.29	4.0	0.71	0.68

[4] Please note that participant stated that during the calculation of values of ^{3}H activity per unit mass for both the AB and B1 sample types an expired radioactive source was used contributing to the observed deviations from the assigned values.

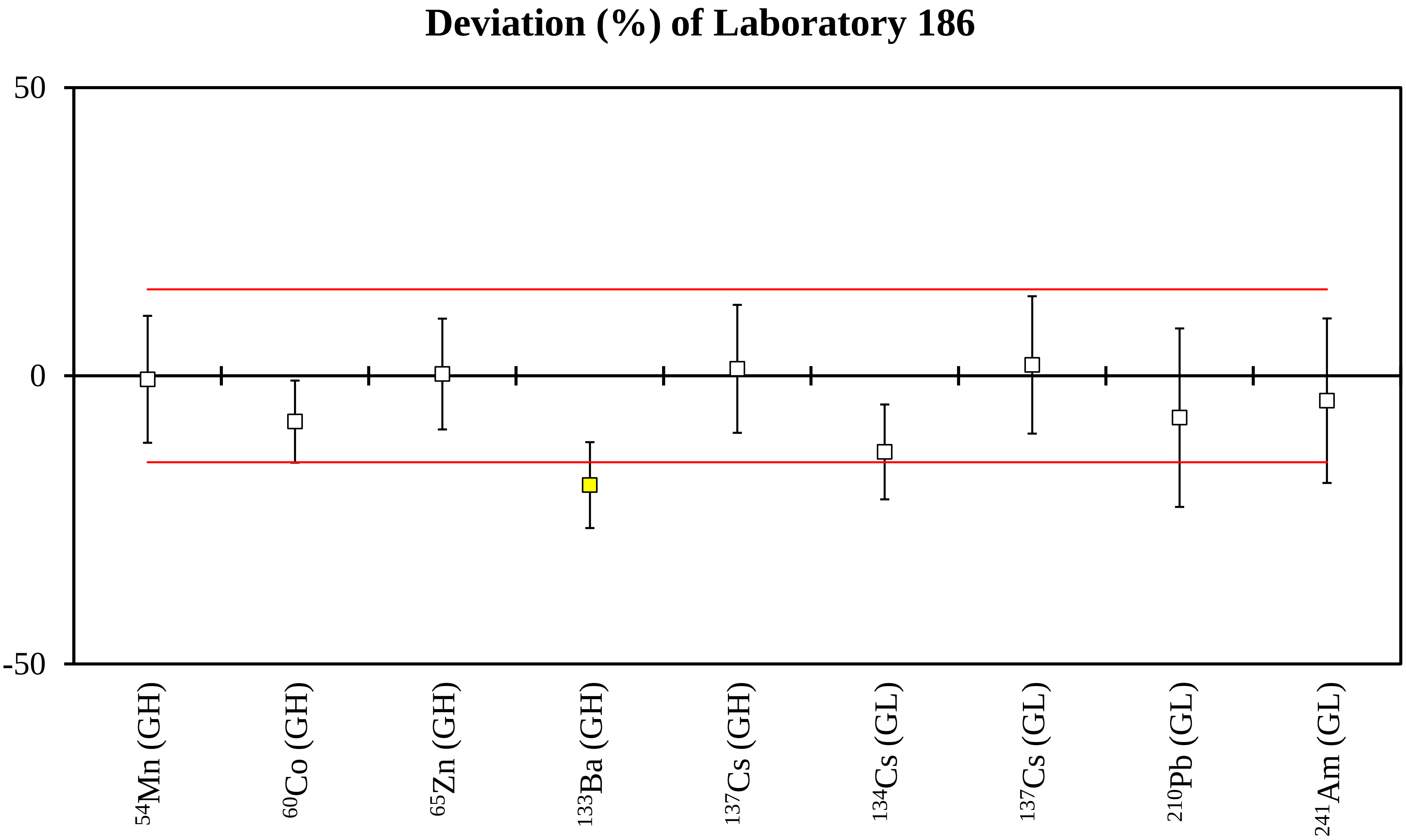

Deviation (%) of Laboratory 180
50
0
-50
^{3}H (B1)
^{14}C (B1)
^{99}Tc (B1)

Radionuclide	Laboratory 180	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (B1)	0.626 ± 0.022	0.5885 ± 0.0081	6.4	1.60	1.09
^{14}C (B1)	0.433 ± 0.030	0.4769 ± 0.0044	−9.2	−1.45	−1.58
^{99}Tc (B1)	0.199 ± 0.014	0.2076 ± 0.0025	−4.1	−0.60	−0.71

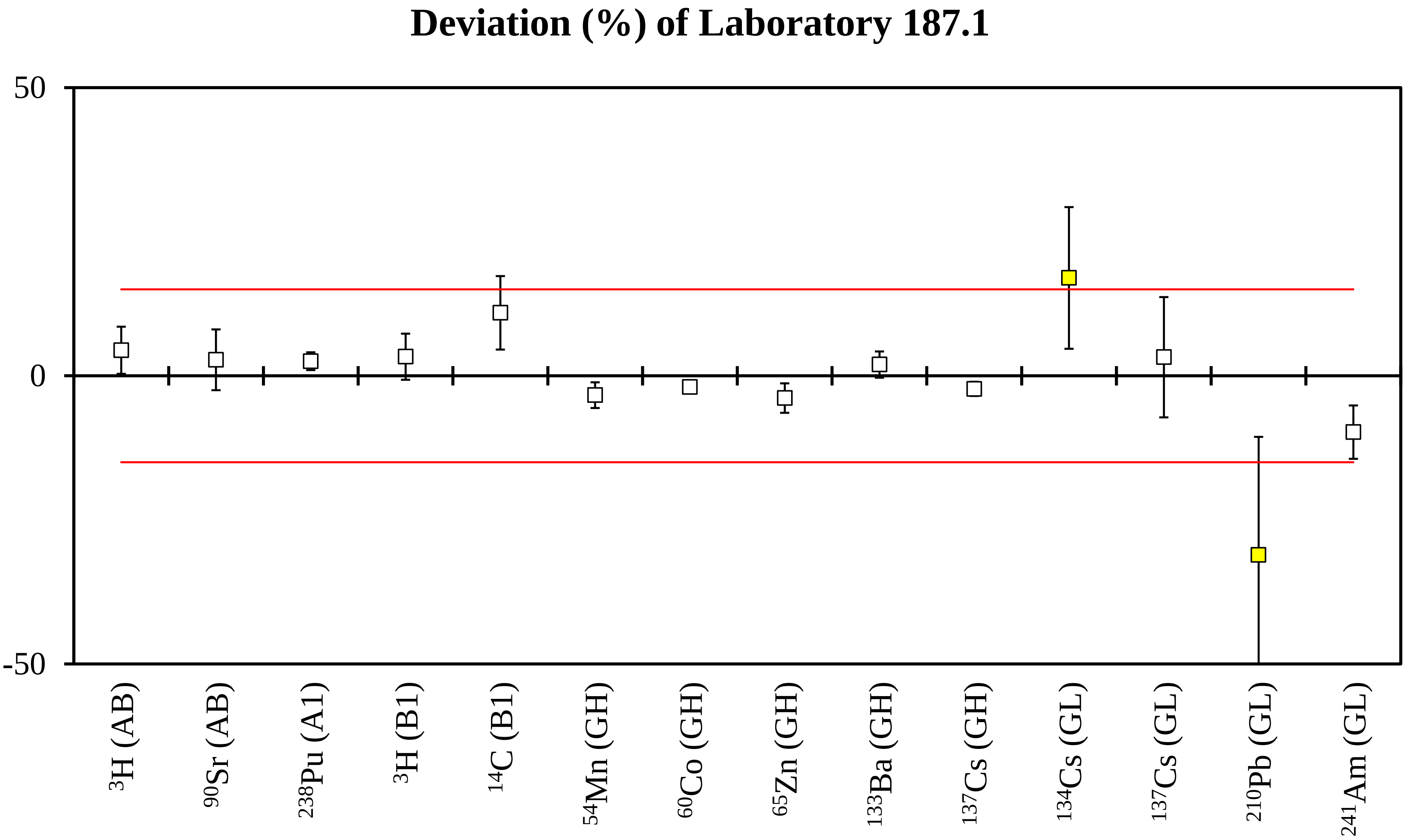


Deviation (%) of Laboratory 183
50
0
-50
54Mn (GH)
60Co (GH)
65Zn (GH)
133Ba (GH)
137Cs (GH)
134Cs (GL)
137Cs (GL)
210Pb (GL)
241Am (GL)

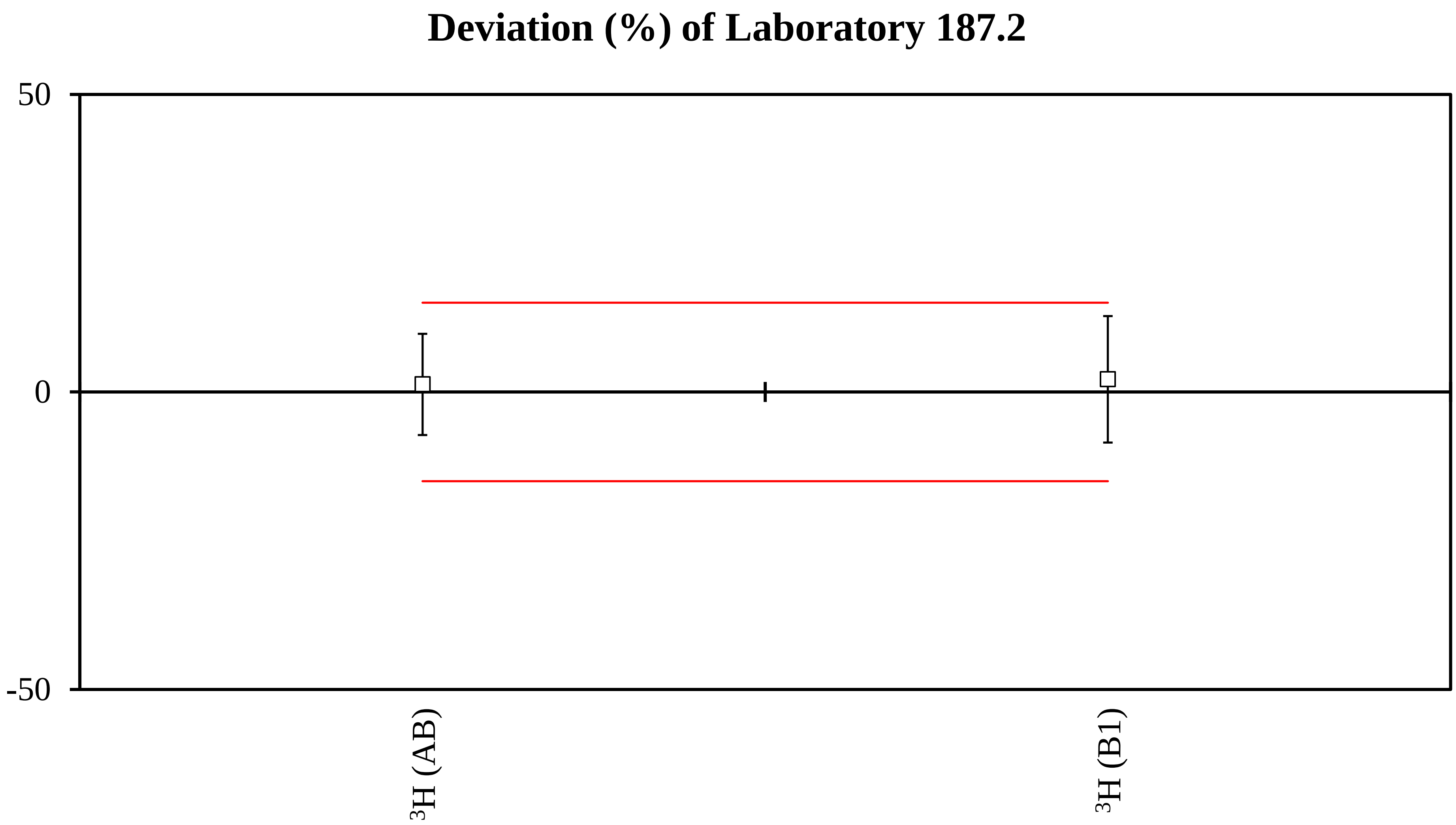
Radionuclide	Laboratory 183	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{54}Mn (GH)	4.994 ± 0.057	5.091 ± 0.029	−1.9	−1.52	−0.33
^{60}Co (GH)	2.338 ± 0.056	2.3900 ± 0.0095	−2.2	−0.92	−0.37
^{65}Zn (GH)	2.587 ± 0.039	2.612 ± 0.023	−1.0	−0.55	−0.16
^{133}Ba (GH)	26.7 ± 1.1	28.26 ± 0.20	−5.5	−1.40	−0.95
^{137}Cs (GH)	38.94 ± 0.65	39.72 ± 0.29	−2.0	−1.10	−0.34
^{134}Cs (GL)	10.64 ± 0.31	10.600 ± 0.076	0.4	0.13	0.06
^{137}Cs (GL)	6.62 ± 0.23	6.733 ± 0.061	−1.7	−0.47	−0.29
^{210}Pb (GL)	18.8 ± 2.0	23.94 ± 0.25	−21.5	−2.55	−3.69
^{241}Am (GL)	23.56 ± 0.41	23.83 ± 0.10	−1.1	−0.64	−0.19


Deviation (%) of Laboratory 186
50
0
-50
54Mn (GH)
60Co (GH)
65Zn (GH)
133Ba (GH)
137Cs (GH)
134Cs (GL)
137Cs (GL)
210Pb (GL)
241Am (GL)

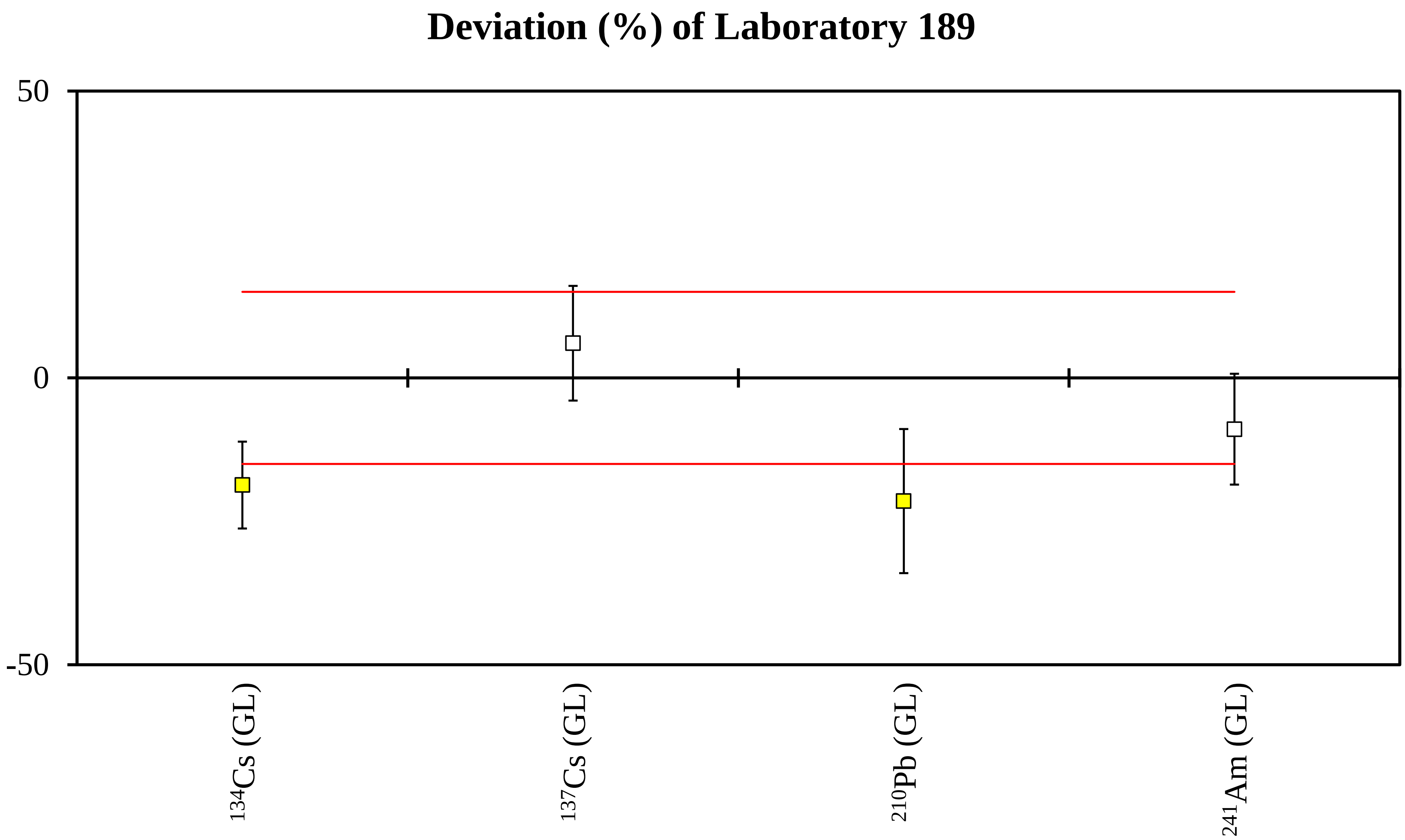
Radionuclide	Laboratory 186	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{54}Mn (GH)	5.06 ± 0.56	5.091 ± 0.029	−0.6	−0.06	−0.10
^{60}Co (GH)	2.20 ± 0.17	2.3900 ± 0.0095	−7.9	−1.12	−1.37
^{65}Zn (GH)	2.62 ± 0.25	2.612 ± 0.023	0.3	0.03	0.05
^{133}Ba (GH)	22.9 ± 2.1	28.26 ± 0.20	−19.0	−2.54	−3.26
^{137}Cs (GH)	40.2 ± 4.4	39.72 ± 0.29	1.2	0.11	0.21
^{134}Cs (GL)	9.20 ± 0.87	10.600 ± 0.076	−13.2	−1.60	−2.27
^{137}Cs (GL)	6.86 ± 0.80	6.733 ± 0.061	1.9	0.16	0.32
^{210}Pb (GL)	22.2 ± 3.7	23.94 ± 0.25	−7.3	−0.47	−1.25
^{241}Am (GL)	22.8 ± 3.4	23.83 ± 0.10	−4.3	−0.30	−0.74


Deviation (%) of Laboratory 187.1
50
0
-50
3H (AB)
90Sr (AB)
238Pu (A1)
3H (B1)
14C (B1)
54Mn (GH)
60Co (GH)
65Zn (GH)
133Ba (GH)
137Cs (GH)
134Cs (GL)
137Cs (GL)
210Pb (GL)
241Am (GL)

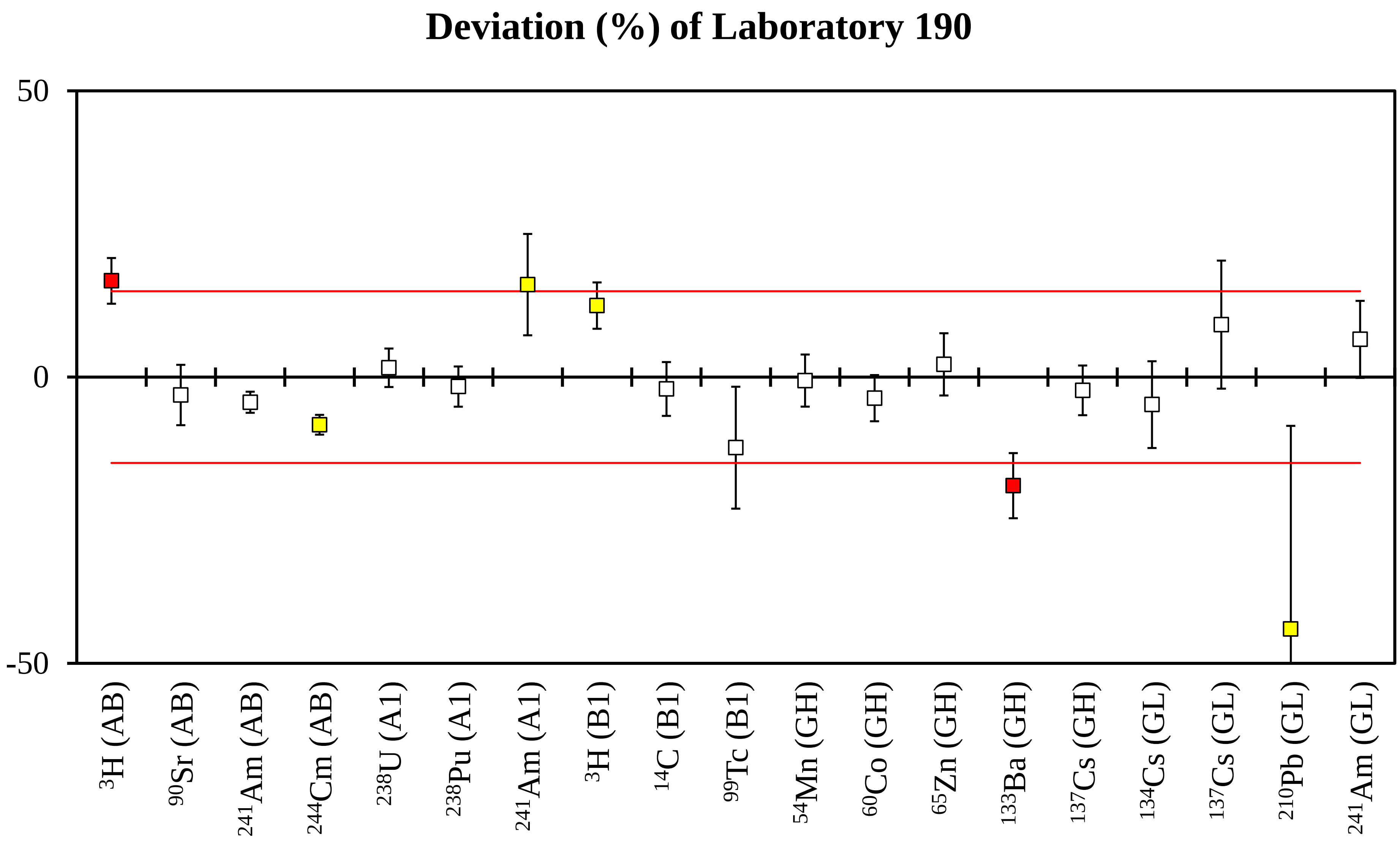
Radionuclide	Laboratory 187.1	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	14.85 ± 0.56	14.22 ± 0.15	4.4	1.09	0.76
^{90}Sr (AB)	6.44 ± 0.33	6.266 ± 0.016	2.8	0.53	0.48
^{238}Pu (A1)	2.224 ± 0.033	2.1690 ± 0.0054	2.5	1.64	0.44
^{3}H (B1)	0.608 ± 0.022	0.5885 ± 0.0081	3.3	0.83	0.57
^{14}C (B1)	0.529 ± 0.030	0.4769 ± 0.0044	10.9	1.72	1.88
^{54}Mn (GH)	4.92 ± 0.11	5.091 ± 0.029	−3.4	−1.50	−0.58
^{60}Co (GH)	2.344 ± 0.024	2.3900 ± 0.0095	−1.9	−1.78	−0.33
^{65}Zn (GH)	2.511 ± 0.063	2.612 ± 0.023	−3.9	−1.51	−0.66
^{133}Ba (GH)	28.81 ± 0.61	28.26 ± 0.20	1.9	0.86	0.33
^{137}Cs (GH)	38.82 ± 0.40	39.72 ± 0.29	−2.3	−1.82	−0.39
^{134}Cs (GL)	12.4 ± 1.3	10.600 ± 0.076	17.0	1.38	2.92
^{137}Cs (GL)	6.95 ± 0.70	6.733 ± 0.061	3.2	0.31	0.55
^{210}Pb (GL)	16.5 ± 4.9	23.94 ± 0.25	−31.1	−1.52	−5.34
^{241}Am (GL)	21.5 ± 1.1	23.83 ± 0.10	−9.8	−2.11	−1.68


Deviation (%) of Laboratory 187.2
50
0
-50
3H (AB)
3H (B1)

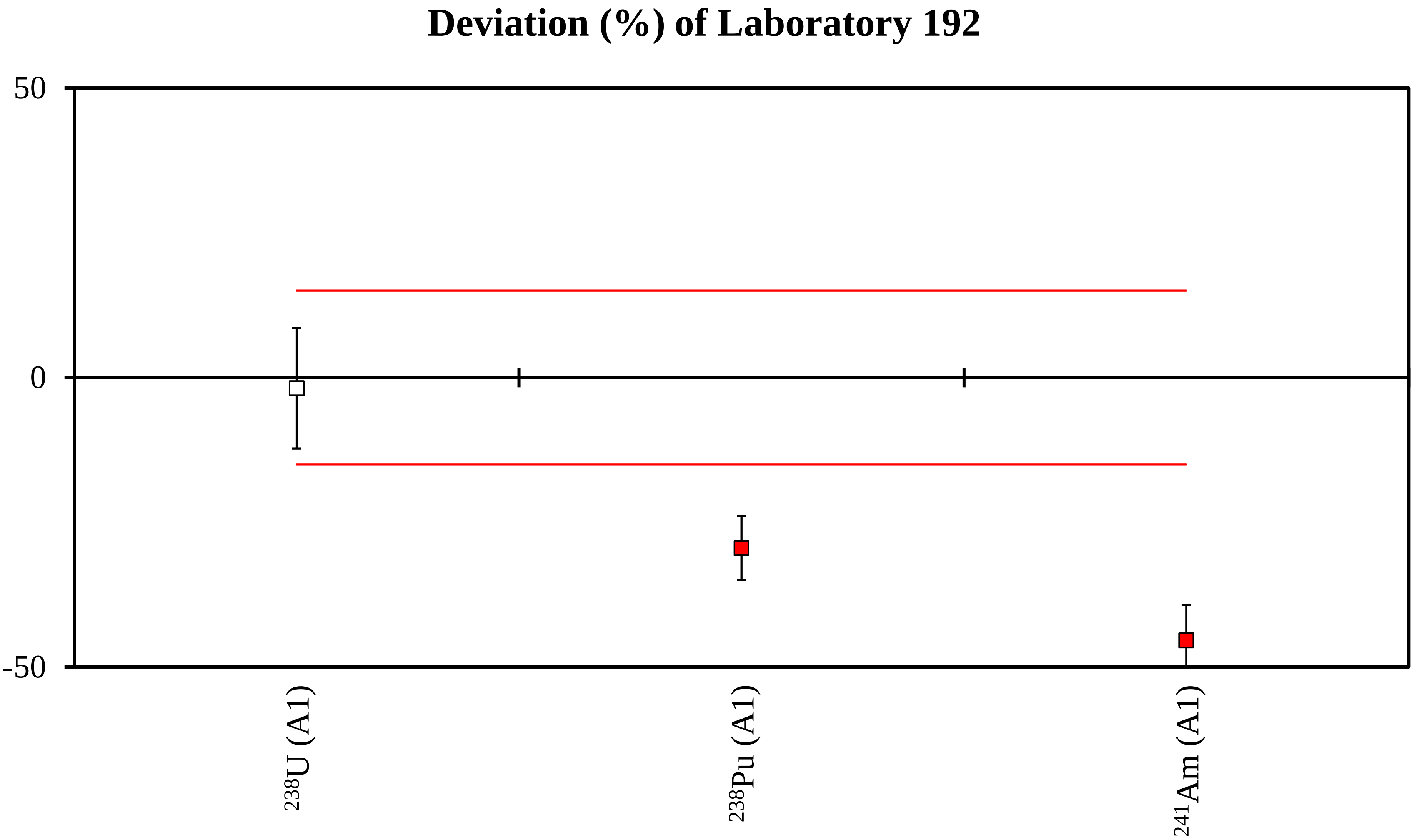
Radionuclide	Laboratory 187.2	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	14.4 ± 1.2	14.22 ± 0.15	1.3	0.15	0.22
^{3}H (B1)	0.601 ± 0.062	0.5885 ± 0.0081	2.1	0.20	0.36


Deviation (%) of Laboratory 189
50
0
-50
134Cs (GL)
137Cs (GL)
210Pb (GL)
241Am (GL)

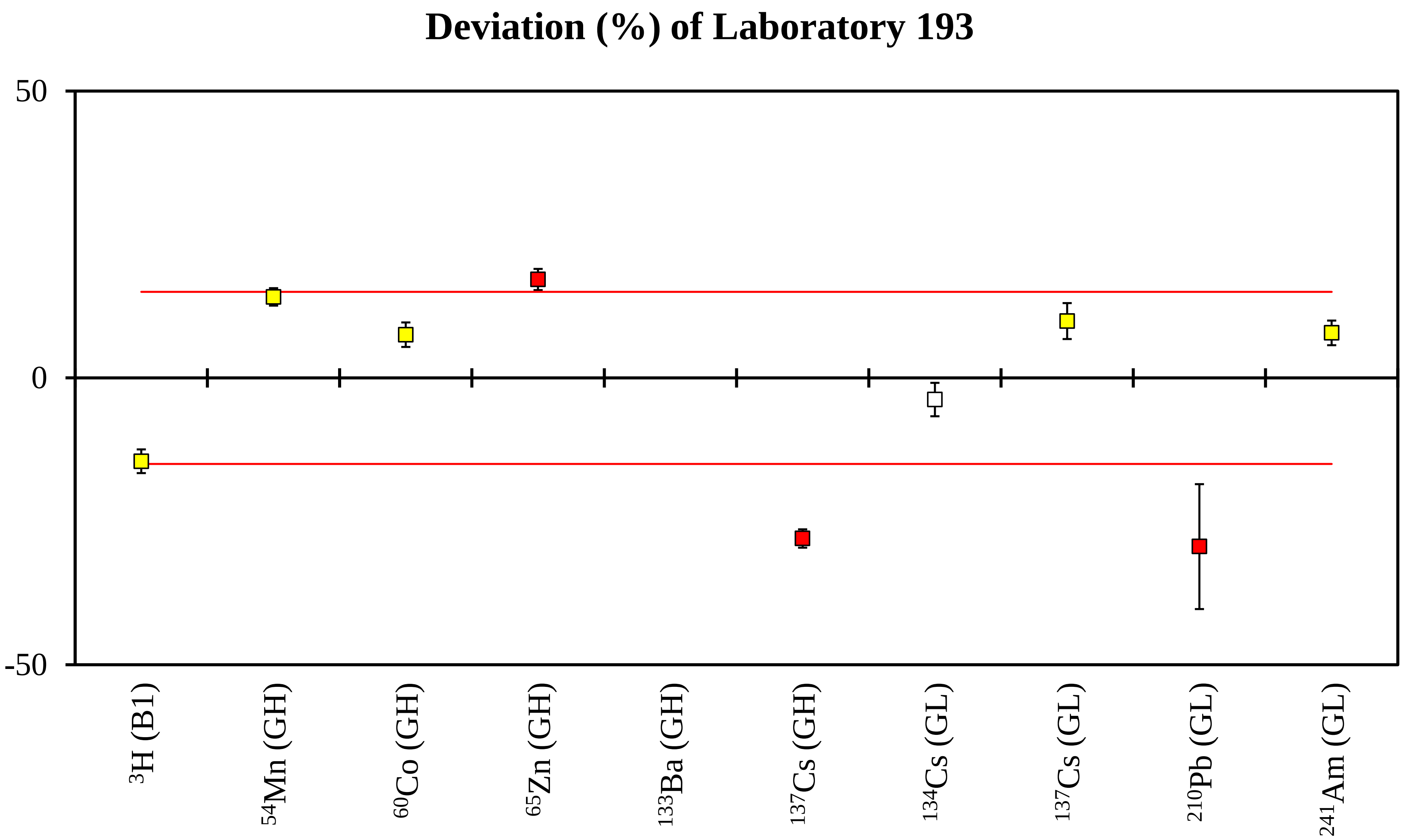
Radionuclide	Laboratory 189	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{134}Cs (GL)	8.62 ± 0.80	10.600 ± 0.076	−18.7	−2.46	−3.21
^{137}Cs (GL)	7.14 ± 0.67	6.733 ± 0.061	6.0	0.60	1.04
^{210}Pb (GL)	18.8 ± 3.0	23.94 ± 0.25	−21.5	−1.71	−3.69
^{241}Am (GL)	21.7 ± 2.3	23.83 ± 0.10	−8.9	−0.93	−1.54


Deviation (%) of Laboratory 190
50
0
-50
3H (AB)
90Sr (AB)
241Am (AB)
244Cm (AB)
238U (A1)
238Pu (A1)
241Am (A1)
3H (B1)
14C (B1)
99Tc (B1)
54Mn (GH)
60Co (GH)
65Zn (GH)
133Ba (GH)
137Cs (GH)
134Cs (GL)
137Cs (GL)
210Pb (GL)
241Am (GL)

Radionuclide	Laboratory 190	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	16.61 ± 0.54	14.22 ± 0.15	16.8	4.26	2.89
^{90}Sr (AB)	6.07 ± 0.33	6.266 ± 0.016	−3.1	−0.59	−0.54
^{241}Am (AB)	7.42 ± 0.14	7.761 ± 0.031	−4.4	−2.38	−0.75
^{244}Cm (AB)	4.634 ± 0.087	5.0547 ± 0.0073	−8.3	−4.82	−1.43
^{238}U (A1)	4.94 ± 0.14	4.861 ± 0.083	1.6	0.49	0.28
^{238}Pu (A1)	2.133 ± 0.076	2.1690 ± 0.0054	−1.7	−0.47	−0.29
^{241}Am (A1)	18.4 ± 1.4	15.841 ± 0.067	16.2	1.83	2.77
^{3}H (B1)	0.662 ± 0.022	0.5885 ± 0.0081	12.5	3.14	2.14
^{14}C (B1)	0.467 ± 0.022	0.4769 ± 0.0044	−2.1	−0.44	−0.36
^{99}Tc (B1)	0.182 ± 0.022	0.2076 ± 0.0025	−12.3	−1.16	−2.12
^{54}Mn (GH)	5.06 ± 0.23	5.091 ± 0.029	−0.6	−0.13	−0.10
^{60}Co (GH)	2.302 ± 0.096	2.3900 ± 0.0095	−3.7	−0.91	−0.63
^{65}Zn (GH)	2.67 ± 0.14	2.612 ± 0.023	2.2	0.41	0.38
^{133}Ba (GH)	22.9 ± 1.6	28.26 ± 0.20	−19.0	−3.32	−3.26
^{137}Cs (GH)	38.8 ± 1.7	39.72 ± 0.29	−2.3	−0.53	−0.40
^{134}Cs (GL)	10.09 ± 0.80	10.600 ± 0.076	−4.8	−0.63	−0.83
^{137}Cs (GL)	7.35 ± 0.75	6.733 ± 0.061	9.2	0.82	1.57
^{210}Pb (GL)	13.4 ± 8.5	23.94 ± 0.25	−44.0	−1.24	−7.56
^{241}Am (GL)	25.4 ± 1.6	23.83 ± 0.10	6.6	0.98	1.13


Deviation (%) of Laboratory 192
50
0
-50
238U (A1)
238Pu (A1)
241Am (A1)

Radionuclide	Laboratory 192	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{238}U (A1)	4.77 ± 0.50	4.861 ± 0.083	−1.9	−0.18	−0.32
^{238}Pu (A1)	1.53 ± 0.12	2.1690 ± 0.0054	−29.5	−5.32	−5.06
^{241}Am (A1)	8.65 ± 0.96	15.841 ± 0.067	−45.4	−7.47	−7.80


Deviation (%) of Laboratory 193
50
0
-50
3H (B1)
54Mn (GH)
60Co (GH)
65Zn (GH)
133Ba (GH)
137Cs (GH)
134Cs (GL)
137Cs (GL)
210Pb (GL)
241Am (GL)

Radionuclide	Laboratory 193	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (B1)	0.503 ± 0.010	0.5885 ± 0.0081	−14.5	−6.64	−2.50
^{54}Mn (GH)	5.81 ± 0.07	5.091 ± 0.029	14.1	9.49	2.43
^{60}Co (GH)	2.570 ± 0.050	2.3900 ± 0.0095	7.5	3.54	1.29
^{65}Zn (GH)	3.060 ± 0.040	2.612 ± 0.023	17.2	9.71	2.95
^{133}Ba (GH)	44.70 ± 0.90	28.26 ± 0.20	58.2	17.83	9.99
^{137}Cs (GH)	28.6 ± 0.6	39.72 ± 0.29	−28.0	−16.69	−4.81
^{134}Cs (GL)	10.2 ± 0.3	10.600 ± 0.076	−3.8	−1.29	−0.65
^{137}Cs (GL)	7.40 ± 0.20	6.733 ± 0.061	9.9	3.19	1.70
^{210}Pb (GL)	16.9 ± 2.6	23.94 ± 0.25	−29.4	−2.70	−5.05
^{241}Am (GL)	25.70 ± 0.50	23.83 ± 0.10	7.8	3.67	1.35

10. DISCUSSION

Accurate and precise measurement of the activity per unit mass of radionuclides in the environment is critical for the assessment of the radiological impact and risk to the public and environment. The following section discusses the reported results for the 2021 Environmental Proficiency Test Exercise. 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 a subset of participants (for each radionuclide) who did report such information. For NPL to provide performance-related feedback, it is encouraged that participants detail the methods and techniques used.

10.1 Tritium in AB

As in the 2020 exercise, the main difficulty in measuring the activity per unit mass of ^{3}H in the AB sample type is the separation of the ^{3}H from the ^{90}Sr spectrum either by chemical separation or by setting regions of interest during measurement. Of the results submitted 86 % were in agreement, 5 % were questionable and 10 % were discrepant. From the range of results provided there does not appear to be any systematic bias between participants' results and the NPL value. This is an improvement on the 2020 exercise where 73 % were in agreement, 14 % were questionable and 14 % were discrepant.

Of those who reported the detection technique, all (19) stated that they used LSC to measure ^{3}H. Specific instruments reported as being used included a HIDEX 300 SL. Quench is always present in aqueous samples and the degree of quench varies between samples. This means that for accurate results a quench correction should be carried out for each sample. A quench curve is often required and it must be specific to the type of sample being measured. A single quench curve is only valid for a given instrument, type of scintillation cocktail, and ratio of sample to scintillation cocktail. The majority (80 %) of the participants who provided details of their methods achieved separation between ^{90}Sr and ^{3}H using either combustion, distillation or pyrolysis. Distillation was the most commonly used, with 11 of the 19 reporting participants', reporting it as the separation technique for ^{3}H in the AB sample type.

10.2 Strontium-90 in AB

There are only two radioactive isotopes of strontium of significance in radiological measurements in the environment: ^{89}Sr and ^{90}Sr. Strontium-90 is the more significant from an environmental protection perspective most likely due to its comparatively long half-life (28.1 a) Strontium-90 is a high fission yield product and has been released into the environment in large amounts following nuclear weapon tests, nuclear power plant incidents, and nuclear fuel reprocessing industries.

The main difficulty in measuring the ^{90}Sr activity per unit mass is the need for a radiochemical separation from the other radionuclides present in the sample, combined with the presence of ^{89}Sr which may interfere with the measurement of ^{90}Sr. Again, several methods consisting of various techniques may be used, including decay and/or ingrowth counting, separation of ^{90}Y followed by Cerenkov and LSC counting and/or spectral deconvolution.

Out of the reported results, 90 % were in agreement and 10 % were questionable. Of the reporting laboratories 21 of the 18 provided techniques form. As with the 2019 and 2020 exercises, the most common separation technique was extraction chromatography (7). Of the laboratories stating extraction chromatography, many reported using the crown-ether-based Sr resin from either TrisKem International or Eichrom Technologies. A couple of other laboratories reported using precipitation of Sr as a carbonate or oxalate followed by dissolution with fuming nitric.

Laboratories reported using detection techniques including Cherenkov counting (6), LSC (5) proportional counting (7). In four instances the chemical yield was determined using ICP-MS measurement of stable Sr (^{88}Sr). Other laboratories opted to use ^{85}Sr (4) as an internal tracer measuring the recovery using gamma spectrometry. Parallel standards containing ^{90}Sr were also used (2).

The PPM of Cherenkov counting, LSC and proportional counting results were as follows:

Cherenkov Counting:	(6.07 ± 0.15) Bq g^{-1}
Liquid Scintillation Counting:	(6.48 ± 0.21) Bq g^{-1}
Proportional Counting:	(6.31 ± 0.19) Bq g^{-1}

No significant bias is observed between results obtained by the various detection techniques. As with the 2020 exercise, due to the size of the dataset and the varied methods leading up to the final analysis, it is not possible to conclude whether the results obtained with these techniques are equivalent.

10.3 Americium-241 in AB

Americium is a beta decay product from ^{241}Pu produced in nuclear reactors. Americium-241 is the most significant radioisotope of americium for environmental measurements as the other long-lived isotope ^{243}Am is produced in nuclear reactors in smaller activities compared to ^{241}Am.

Americium-241 can be measured by three different measurement techniques: alpha spectrometry, gamma spectrometry and mass spectrometry. The main difficulty in measuring the ^{241}Am activity per unit mass with alpha spectrometry is the need for a radiochemical separation from the other radionuclides present in the sample. Although not present in the AB this is especially true for the ^{238}Pu 5.46 MeV and 5.50 MeV peaks which interfere with the 5.44 MeV and 5.49 MeV peaks of ^{241}Am.

This year's exercise saw 18 results submitted for ^{241}Am in AB sample type. Of these results, all were in agreement. All but two participants who reported their detection technique measured ^{241}Am using alpha spectrometry with the other two opting for gamma spectrometry. Sources for alpha spectrometry were prepared using electrodeposition which provides good spectral resolution. All participants who reported a tracer being used (11) stated that they used ^{243}Am as a chemical yield tracer.

10.4 Curium-244 in AB

This nuclide is produced by multiple neutron activation of ^{238}U, ^{239}Pu and ^{243}Am. It decays by emission of alpha particles to ^{240}Pu. It occurs in the environment as a result of weapon tests and discharges from the nuclear industry. The main difficulty in measuring the ^{244}Cm activity per unit mass is the need for a radiochemical separation from the other radionuclides present in the sample and the absence of a suitable curium chemical yield tracer. Americium is often considered a chemical analogue for curium but as separations get more specific the suitability of americium becomes limited. This year's exercise saw 16 results for ^{244}Cu in A1. Of the results submitted 81 % were in agreement, 13 % were questionable and 6 % were discrepant.

A couple of participants opted to use a pre-concentration step before separation with going for co-precipitation and the other evaporation. Separation of ^{244}Cm was achieved using ion exchange (5), with two laboratories explicitly stating anion exchange. Extraction chromatography (2) or a combination of the ion exchange and extraction chromatography (1) was also used. One laboratory used liquid-liquid extraction and obtained results in agreement with the assigned value. There is no indication that there are significant differences between the results obtained from the various techniques used.

All participants that reported a detection technique stated that they used alpha spectrometry (13) and ^{243}Am was the only reported tracer (11).

10.5 Uranium-238 in A1

Uranium-238 can be measured by alpha spectrometry, gamma spectrometry (of decay products) and mass spectrometry. The main difficulty in measuring the ^{238}U activity per unit mass with alpha spectrometry is the need for a radiochemical separation from the other radionuclides present in the sample. This year's exercise saw 16 results reported for ^{238}U in the A1 sample type. Of these results, 88 % were in agreement, 6 % were questionable and 6 % were discrepant.

Various radiochemistry techniques were adopted by participating laboratories for the A1 mix. Separation was achieved using ion exchange (7), with two laboratories explicitly stating anion exchange, and extraction chromatography (3) or a combination of the two.

Detection was achieved using alpha spectrometry (13) and mass spectrometry (1). Sources were prepared for measurement by alpha spectrometry by using electrodeposition. The mass spectrometry method involved the chemical separation of the ^{238}U, ^{238}Pu and ^{241}Am and measurement by ICP-MS (inductively coupled mass spectrometry) using thallium as an internal standard.

10.6 Plutonium-238 in A1

The main difficulty in measuring the ^{238}Pu activity per unit mass with alpha spectrometry is the need for a radiochemical separation of the sample (especially the ^{241}Am 5.44 MeV and 5.49 MeV peaks which interfere with the 5.46 MeV and 5.50 MeV peaks of ^{238}Pu). It is possible to determine ^{238}Pu by gamma spectrometry, although the emission probability (0.0397(8) %) and energy for the 43 keV peak are low meaning it is unfeasible at the activity per unit mass of this exercise here. This year's exercise saw 18 results for ^{238}Pu in A1, four more results than submitted for the 2020 exercise. Of the results submitted 67 % were in agreement with the assigned value up from 50 % in the 2020 exercise.

Recovery was traced using ^{236}Pu (2) and ^{242}Pu (12) following radiochemical separation. Radiochemical separation was performed using a variety of methods which included anion/cation exchange (6), extraction chromatography (4) or a combination of the two (2). All participants who disclosed their detection technique used alpha spectrometry (16). Sources for alpha spectrometry were prepared using electrodeposition (5) and microprecipitation (1). The microprecipitation method for ^{238}Pu used cerium fluoride which was collected on a Resolve™ filter after radiochemical separation using TRU resin; an extraction chromatographic resin containing octylphenyl-N,N-di-isobutyl carbamoylphosphine oxide (CMPO) dissolved in tri-n-butyl phosphate (TBP).

Detection of ^{238}Pu was achieved using alpha spectrometry (16). Sources were prepared for measurement by alpha spectrometry by using electrodeposition (5) with one participant using microprecipitation. The microprecipitation method involved microprecipitation of ^{238}Pu with cerium fluoride and collecting the precipitate on a Resolve™ filter. The recovery of ^{238}Pu was traced using the following radionuclides ^{242}Pu (12), ^{236}Pu (2).

10.7 Americium-241 in A1

As stated for the AB sample type, ^{241}Am can be measured by three different measurement techniques: alpha spectrometry, gamma spectrometry and mass spectrometry. This year's exercise saw 19 results submitted for ^{241}Am in the A1 sample type, one more than for the AB sample type (18). Of these results, 63 % were in agreement, 16 % were questionable and 21 % were discrepant.

Americium-241 in the A1 sample type was measured by both alpha spectrometry (13) and gamma spectrometry (3). As with the ^{238}Pu, sources were prepared for alpha spectrometry by electrodeposition (4) and microprecipitation with cerium fluoride (1). All participants who reported a tracer being used (12) stated that they used ^{243}Am as a chemical yield tracer.

The PPM of alpha spectrometry and gamma spectrometry results were as follows:

Alpha Spectrometry:	(13.69 ± 0.90) Bq g^{-1}
Gamma Spectrometry:	(16.78 ± 0.79) Bq g^{-1}

These results suggest there may be a significant difference between results obtained by alpha and gamma spectrometry. As with the 2020 exercise, due to the size of the dataset and the varied methods leading up to the final analysis, it is difficult to draw definitive conclusions. There are three values measured by alpha spectrometry biased significantly low (~7-8 %), which may reflect the relative difficulty of alpha spectrometry vs gamma spectrometry measurements of ^{241}Am.

10.8 Tritium in B1

The main difficulty in measuring the tritiated water activity per unit mass is the need for a radiochemical separation from other beta-emitters i.e. ^{14}C and ^{99}Tc in the B1 sample type. The B1 sample matrix is an alkaline solution.

This year's exercise saw 31 results reported, which is a similar number of results submitted to the 2020 exercise (30). Of the results submitted 81 % were in agreement, 13 % were questionable and 6 % were discrepant. All participants who reported their techniques (27) stated that they used LSC to measure the ^{3}H.Tritium undergoes beta-decay, with an E_{max} = 18.6 keV, to ^{3}He.

Of the participants who described their methodologies, 18 used distillation to isolate ^{3}H from other interfering radionuclides. A few participants opted for a combustion-based technique where ^{3}H was trapped in nitric acid and ^{14}C into Carbosorb.

10.9 Carbon-14 in B1

The main difficulty in measuring the activity per unit mass of ^{14}C in B1 is the need for a radiochemical separation from ^{3}H, and ^{99}Tc. Of the results submitted 78 % were in agreement, 13 % were questionable and 9 % were discrepant which was similar to that of the 2020 exercise.

Most participants used $[^{14}C]O_2$ gas generation (either by sample combustion or the addition of acid to the sample) as the separation technique. All 21 reporting participants stated that they used LSC to measure ^{14}C.

10.10 Technitium-99 in B1

This long-lived nuclide is produced by neutron-induced fission of ^{235}U and ^{239}Pu. It undergoes beta-decay (E_{max} = 294 keV) to ^{99}Ru. It occurs widely in the marine environment as a result of discharges from the nuclear industry. The main difficulty in measuring the ^{99}Tc activity per unit mass is the need for a radiochemical separation from ^{3}H, and ^{14}C in the B1 sample type.

Technitium-99 had the lowest number of reported values for the B1 sample type with 16 reported results. It also saw the largest deviation (12.7 %) from the assigned value, this may be attributed to one large positive deviation from laboratory 1. Of the results submitted 88 % were in agreement, 6 % were questionable and 6 % were discrepant.

Radiochemical separation of ^{99}Tc from the other beta-emitters was achieved using a wide variety of techniques including, solvent extractions (2), ion-exchange chromatography (2) and extraction chromatography using extraction-based chromatography resins including TEVA (TrisKem International).

Technitium-99 may be measured by multiple detection techniques including mass spectrometry, liquid scintillation counting, gas-flow proportional counting or low-level beta counting. Participants reported using both mass spectrometry (5) and LSC (9). The chemical yield was traced by ^{99m}Tc (4), stable Re (1) or parallel standards of ^{99}Tc (4).

The PPM of mass spectrometry and liquid scintillation counting results were as follows:

Mass Spectrometry:	(0.2055 ± 0.0076) Bq g^{-1}
Liquid Scintillation Counting:	(0.265 ± 0.070) Bq g^{-1}

The higher result for the LSC is due to a result submitted by laboratory 1 with a deviation of 297 % from the assigned value. Removing that result reduces the deviation from 27.7 % to −5.8 % far closer to the −1.0 % deviation of the mass spectrometry.

10.11 Sample Types GH and GL

A similar number of datasets were provided for 2021 as for the 2020 exercise. As with previous exercises, the samples included radionuclides with a wide range of emission energies.

As with the 2020 exercise, the majority of questionable and discrepant results for the GL sample type were for ^{210}Pb, with 59 % of results submitted for ^{210}Pb agreeing with the assigned value. The GL sample for this year’s exercise contained challengingly low-levels of ^{210}Pb similar to the 2020 exercise and around 10-times more ^{241}Am than ^{210}Pb by activity. Lead-210 is a particularly challenging radionuclide to measure by gamma spectrometry due to its low emission energy (46.5 keV), low emission intensity (~4.3 %), and its ubiquitous presence in gamma-ray detector backgrounds. Although the activity per unit mass of ^{210}Pb in the GL sample type remained similar to the previous exercise, the mean deviation of participants' values from the Assigned Value increased from −4.1 % to −13.4 %.

The relatively low level of performance for ^{210}Pb results may be attributed in part to the composition of commercially-available mixed radionuclide calibration standards. Many mixed radionuclide standards do not include ^{210}Pb (46.5 keV) which has poor solubility in hydrochloric acid and instead use ^{241}Am (59.5 keV). That being said, one laboratory for this year's exercise specifically stated using a ^{210}Pb calibration standard however their result for ^{210}Pb was not in agreement, and it is unlikely the observed bias is due to this one single issue. It is strongly recommended that the efficiency calibration points cover the entire energy range of interest (see for example BS EN ISO 10703:2021, BS EN ISO 20042:2019). When measuring gamma-emitting radionuclides with low emission energies such as ^{210}Pb

and ^{241}Am (59.5 keV) it is also important to determine and apply self-attenuation correction factors relating to sample density. The lower the emission energy, the larger the self-attenuation correction factor. Another important factor in ^{210}Pb measurement is that the majority of high-resolution gamma spectrometers for environmental measurements are enclosed in a lead shield, and unless this contains an inner layer of aged lead there will be a significant background signal due to naturally-occurring ^{210}Pb. Participants reported a range of relative uncertainties for ^{210}Pb between 1.7 % and 35.5 %. NPL encourages participants to review their uncertainty budgets to ensure they are representative and include all relevant sources of uncertainty such as counting statistics, emission probability, background, matrix and geometry corrections etc. For more information on uncertainties relating to gamma spectrometry measurements of environmental samples refer to the 2020 exercise report (van Es et al., 2021).

For the case of ^{134}Cs true coincidence summing of emissions needs to be considered where the source to detector geometry is close. This can be particularly challenging for radionuclides with gamma-ray emissions in coincidence with other low-energy gamma rays or X-rays as the corrections can be large and difficult to determine with accuracy.

The data for ^{134}Cs in this year's GL samples show an improvement over last year (zeta-score improved from −2.71 to −2.04, critical value 2.69) and the results are no longer discrepant. The zeta-score is not significantly worse than that for ^{137}Cs (+1.72) and the deviation plot indicates a largely consistent dataset.

As with previous exercises, the GH sample type saw comparatively few discrepant and questionable results when compared to other sample types. There were relatively more discrepant or potentially discrepant (red or yellow) results on the low side for ^{133}Ba suggesting cascade summing is still an issue for this radionuclide. Correcting for cascade summing is more challenging for electron-capture radionuclides than for beta decay radionuclides such as ^{134}Cs due to the larger number of X-rays produced. There were a few different measurement techniques reported for the GH and GL sample types with the vast majority of measurements being performed using high-resolution gamma spectrometry.

11. REFERENCES

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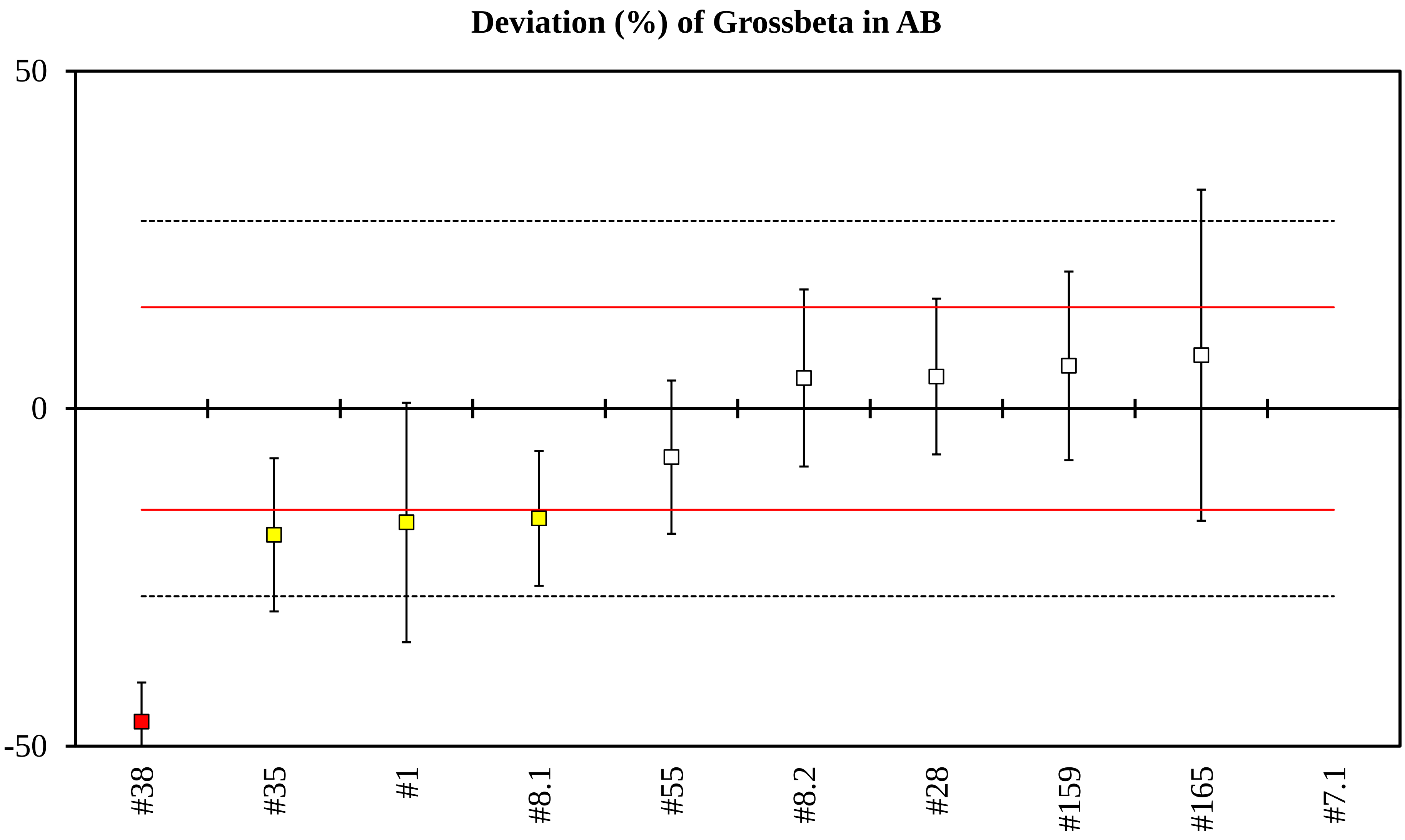
APPENDIX I GROSS MEASUREMENT RESULTS SUMMARY

Following on from the previous exercise a decision was made to not use the PMM as the Assigned Value for the gross 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 the following tables are the PMM of the submitted results and are not traceable to national standards of radioactivity. The PMM of the gross measurements is provided as an indicator and has not been used for performance assessment. It is for this reason results for gross measurements do not appear in the main body of the report.

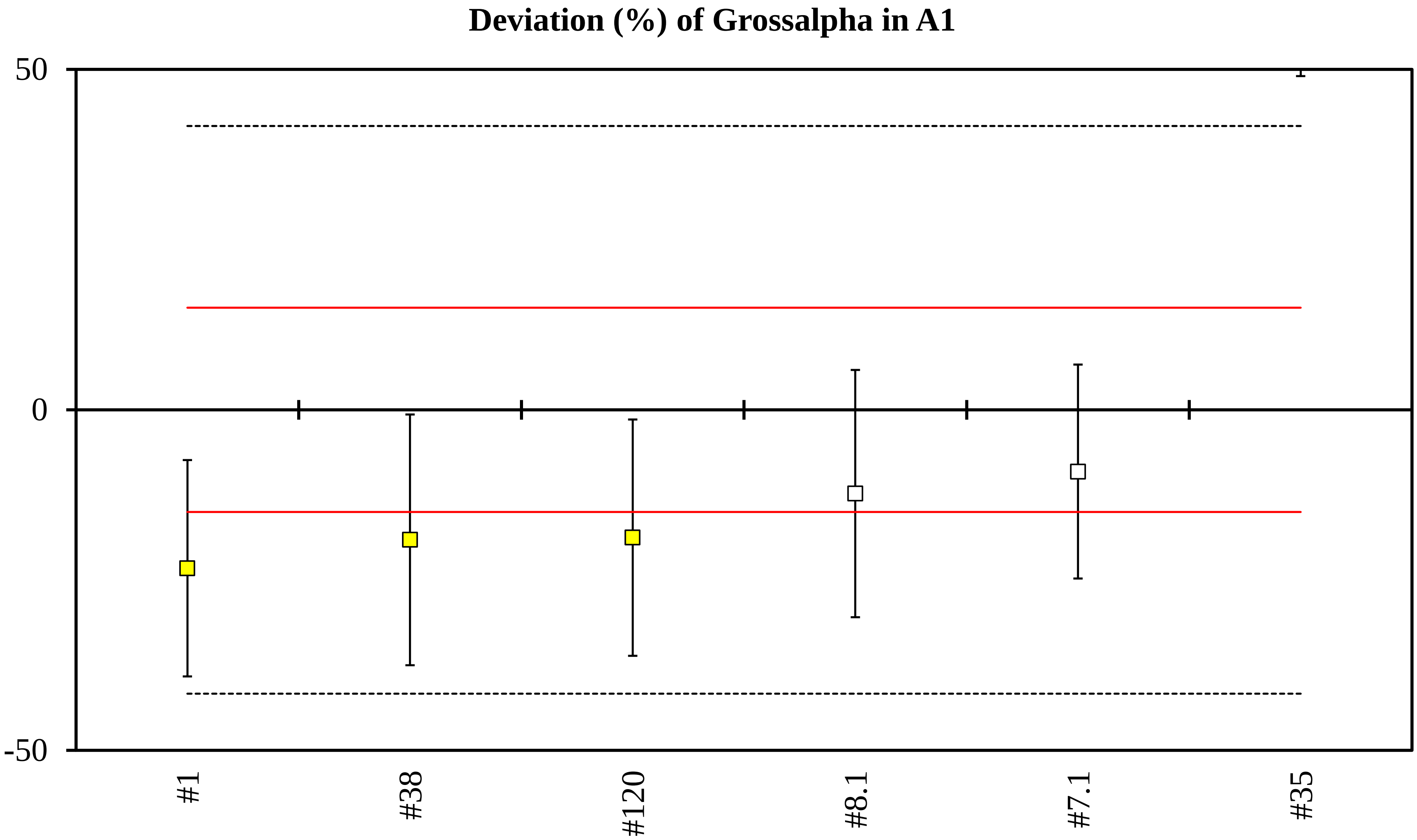
A 1 Gross radionuclide measurements summary

Measurement	PMM
Gross beta (AB)	13.9 ± 1.5 Bq g^{-1}
Gross alpha (A1)	30.9 ± 5.0 Bq kg^{-1}
Gross beta (B1)	0.66 ± 0.20 Bq g^{-1}


Deviation (%) of Grossbeta in AB
50
0
-50
#38
#35
#1
#8.1
#55
#8.2
#28
#159
#165
#7.1

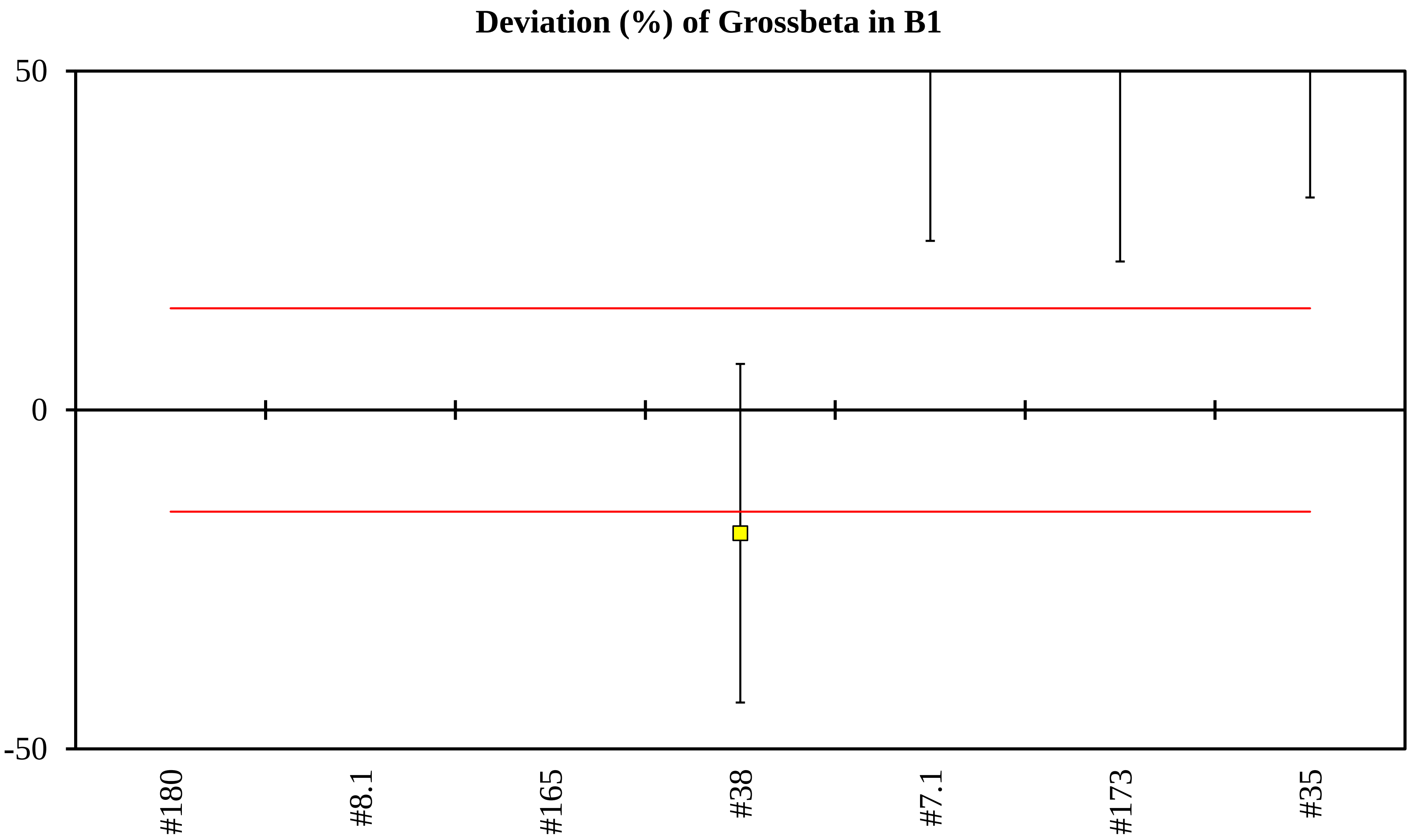
A 2 Gross beta in AB

Laboratory Code	Laboratory Activity/ Bq g^{-1}	Zeta	Z Score	Deviation/ %
1	11.555 ± 2.128	−0.90	−2.90	−17
7.1	26.5 ± 2	5.04	15.57	91
8.1	11.64 ± 0.59	−1.40	−2.79	−16
8.2	14.53 ± 0.93	0.36	0.78	5
28	14.56 ± 0.32	0.43	0.82	5
35	11.3 ± 1	−1.44	−3.21	−19
38	7.45 ± 0.1	−4.29	−7.97	−46
55	12.9 ± 0.742	−0.60	−1.24	−7
159	14.78 ± 1.1085	0.47	1.09	6
165	15 ± 3	0.33	1.36	8


Deviation (%) of Grossalpha in A1
50
0
-50
#1
#38
#120
#8.1
#7.1
#35

A 3 Gross alpha in A1

Laboratory Code	Laboratory Activity/ Bq kg^{-1}	Zeta	Z Score	Deviation/ %
1	23.712 ± 3.0615	−1.23	−3.99	−23
7.1	28.1 ±1.7	−0.53	−1.56	−9
8.1	27.1 ± 3.5	−0.62	−2.11	−12
35	55 ± 1	4.73	13.39	78
38	25 ± 4	−0.92	−3.28	−19
120	25.1 ±3.5	−0.95	−3.22	−19



Deviation (%) of Grossbeta in B1
50
0
-50
#180
#8.1
#165
#38
#7.1
#173
#35

A 4 Gross beta in B1

Laboratory Code	Laboratory Activity/ Bq g^{-1}	Zeta	Z Score	Deviation/ %
7.1	1.2 ± 0.093	2.45	14.05	82
8.1	0.1419 ± 0.007	−2.59	−13.48	−79
35	1.246 ± 0.034	2.89	15.25	89
38	0.54 ± 0.02	−0.60	−3.12	−18
165	0.175 ± 0.035	−2.39	−12.62	−73
173	1.24 ± 0.22	1.95	15.09	88
180	0.1392 ± 0.0074	−2.60	−13.55	−79

[END OF REPORT]